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November 2020

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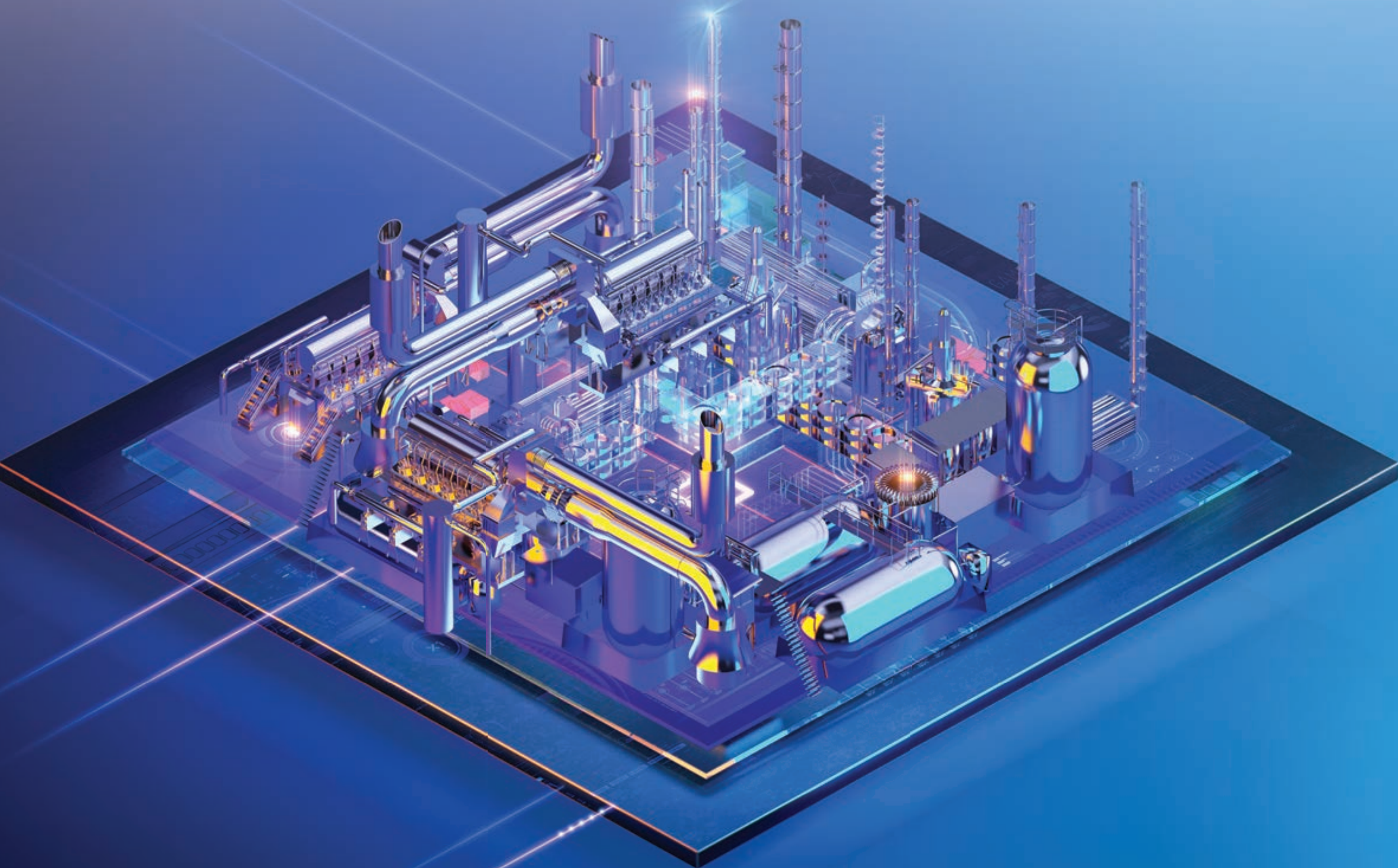

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Cover Story

In the News

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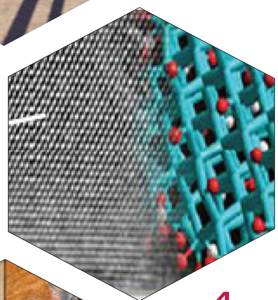
Technical and Practical



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Editor's Page

A heightening interest in hydrogen

Last year, this column addressed hydrogen's potential for playing a significant role in the global search for clean, secure energy sources. This year, the interest in hydrogen has ramped up with a striking number of plans for and developments in hydrogen production and use. While most of the world's hydrogen is currently produced by steam methane reforming (termed "gray" hydrogen), aggressive carbon-reduction goals have turned attention to "green" hydrogen (produced by electrolysis powered by renewable energy sources) and to a lesser extent to "blue" hydrogen (produced from fossil fuels, with carbon capture).

Recent advances in electrolyzer technology have made green hydrogen production more attractive. For more on this, see our September Cover Story (Electrolyzer Technologies for Green Hydrogen, pp. 26–30).

Europe

The European Commission's (EC; www.ec.europa.eu) European Green Deal set the ambitious objective for the E.U. to reach net-zero greenhouse gas emissions by 2050. Green hydrogen plays an important role in the E.U. vision, which includes a phased approach to deploying large-scale renewable hydrogen technologies. Targets include producing up to one million metric tons of renewable hydrogen from now through 2024, and up to ten times that amount from 2025 to 2030. To help put this strategy into action, the EC set up the European Clean Hydrogen Alliance, which includes industrial and governmental leaders, research organizations, the European Investment Bank and more. The long list of members includes familiar names like Air Liquide, BASF, Dow Europe, Shell and many more.

Green hydrogen projects are booming. Recently, Iberdrola (www.iberdrola.com) and Fertiberia (www.fertiberia.com) in Spain, agreed to invest €150 million to construct what is said to be the largest plant to produce green hydrogen for industrial use in Europe. The green hydrogen is slated to be used in an ammonia plant to manufacture green fertilizers.

And electrolyzer demand is up. Enapter (www.enapter.com) for example, has recently announced plans for a new production site in Germany to produce more than 100,000 anion-exchange membrane electrolyzer modules per year.

Worldwide

The surge in green hydrogen is by no means limited to Europe. A $5-billion green-hydrogen-based ammonia production facility, said to be the world's largest green hydrogen project, is planned for the Kingdom of Saudi Arabia. The joint-venture project involves Air Products (www.airproducts.com), ACWA Power (www.acwapower.com) and NEOM (www.neom.com).

In the U.S., Washington state's Douglas County Public Utility District is having a 5-MW proton-exchange membrane electrolyzer installed to produce hydrogen from renewable energy. This will be the largest, and first-of-its-kind system to be used by a public utility in the U.S.

There are many more, significant hydrogen projects underway — you can find details on our website, in our e-newsletters and in the pages of this magazine. And advances in the technologies for hydrogen production and use are continuing to be developed. See, for example several related articles in the Chementator section of this issue (pp. 4–8). ■

Dorothy Lozowski, Editorial Director

Edited by:
Gerald Ondrey

ETHYLENE

Last month, Linde GmbH (Pullach, Germany; www.linde.com) and Shell (den Hague, the Netherlands; www.shell.com) announced an exclusive collaboration agreement on ethane-oxidative dehydrogenation (E-ODH) technology for ethylene production. The catalytic process is an alternative route to ethane steam cracking, offering the potential of economic advantages, acetic acid co-production and significantly lower overall carbon footprint. The two companies have been developing E-ODH independently for many years and this new collaboration brings together their complementary patent positions, expert know-how and common commitment to a lower-carbon future. The agreement will enable accelerated deployment of this novel technology across the wider chemicals sector, with Linde marketing the process under the tradename EDHOX.

Today, ethylene is mainly obtained by steam-cracking technology, which takes place in furnaces operating at temperatures over 900°C. In contrast, Linde's EDHOX technology operates at moderate temperatures (below 400°C), with the corresponding reduction in CO_2 emissions. This catalytic on-purpose ethylene technology takes place in a fixed-bed reactor, where ethane and oxygen react to form ethylene, acetic acid and CO_2. After separation and purification, the pure CO_2 can be stored or used for downstream processing, and the acetic acid co-product can be used for making vinyl acetate monomer, ethylene-vinyl acetate copolymer and polyvinyl alcohol products.

The EDHOX technology was successfully validated for commercial use in a demonstration plant operating since 2017 at Pullach. The plant achieved a high yield of combined ethylene and acetic acid, with an overall selectivity of greater than 93%, according to Linde.

ENGINEERED POLYMER

Submersible pumps, which are predominantly used for agricul-

(Continues on p. 5)

Nanoparticles improve lubricant performance in friction and wear prevention

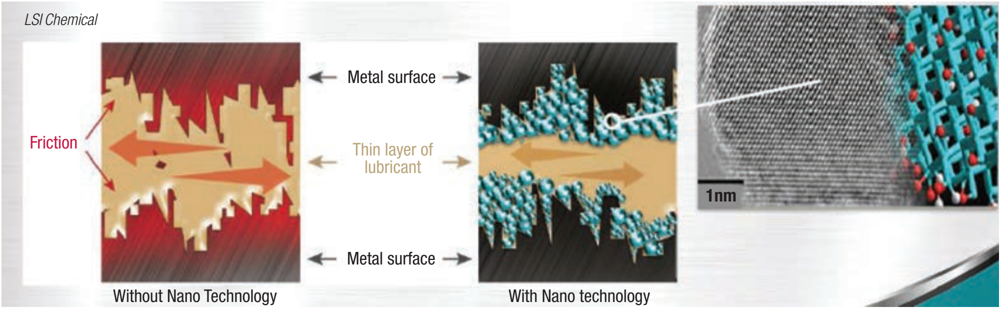
Nanoscale materials have been added to engine lubricants to enhance performance for some time, but the use of such materials has been limited by their inability to remain suspended in the oils, and by their tendency to darken the color of the lubricant. Now, LSI Chemical (Mt. Gilead, Ohio; www.lsichemical.com) has developed a nanoparticle engine-lubricant additive that alleviates these issues, while providing improved anti-wear performance along with less friction.

LSI Chemical, which was spun off in August as a separate company from Lubrication Specialties Inc., has developed the NanoClear series of lubricant additive products for vehicle engines and industrial applications. Its lubricant additives are carbon nanoparticles that have a size range (3–8 nm) and polarity that allows them to act as "tiny ball bearings, filling in asperities of machined metal surfaces to decrease friction," explains Todd Cawley, CEO of LSI Chemical (diagram).

Simultaneously, the nanoparticles decrease engine wear. "These carbon nanoparticles form links with the molecules of the lubricant to make it behave like higher-viscosity oil," Cawley says, which improves wear performance. For example, the company found a 20% reduction in wear when the nanocarbon product was added to a brand-name synthetic 10W-30 motor oil.

To overcome the problem of nanoparticles settling out of oils, LSI developed a unique and proprietary ester compound that combines with the nanoparticles to keep them in suspension and retain the oil's clear appearance for years. In contrast, ceramic nanoparticles settle out of solution in a few hours, Cawley says.

LSI Chemical offers a host of lubricant additive products and is developing others. The company now tests user's lubricant samples to develop an additive package that is customized to the requirements of a particular lubricant type and application.



A sandwich catalyst boosts H_2 production

Platinum has been the main catalyst for hydrogen-producing reactions, but it has a low affinity for water molecules. This results in a slow rate of water electrolysis. Attempts have been made to combine metal-sulfide with platinum nanoparticles that promote water electrolysis, but the unstable nature of platinum/metallic-sulfide surfaces reduces the durability of catalysts.

To overcome those limitations, a research team — led by professor In Su Lee and Soumen Dutta of the Dept. of Chemistry, Pohang University of Science and Technology (Pohang, South Korea; www.postech.ac.kr) — has designed a "sandwich" catalyst consisting of a platinum/metal-hydroxide interface. The team grew a 1-nm platinum layer on the surface of nickel/iron-double-hydroxide, thus synthesizing 2D-2D nanohybrid materials in the form of sandwiches containing 2D-nickel/iron-hydroxide-nano plates.

This synthesized sandwich catalyst has shown more than six times the activity of the conventional catalytic material (20%-Pt/C), and is said to maintain stable catalytic action in the H_2-producing reaction of water electrolysis for more than 50 hours. "Sandwich catalysts have the highest alkali solution hydrogen-producing catalytic activity among substances that do not use carbon supports, but are significantly more durable than similar electrochemical catalysts that are stable for just three to five hours," says Lee.

tural irrigation purposes, are typically placed at several meters below the earth's surface for water extraction. Thrust bearings are highly critical to the life and performance of these pumps. Since these bearings undergo continuous rotation, they will rub against sand, mud and the metal stationary surface of the bearing housing. This causes a rise in temperature during operations. Furthermore, due to the very high underground pressure (1 bar per meter), these parts are also subjected to high temperature and pressure conditions while in operation.

Although sintered-carbon thrust bearings are one of the best available non-metal products for submersible pumps, this material is brittle, which means that parts containing it are often fragile. The processing of these materials is also not easy

DOMO Chemicals GmbH (Leuna, Germany; www.

(Continues on p. 6)

First full integration of H_2 production, distribution, storage and use is underway

The recently launched H2@Scale project is integrating a number of elements necessary for the commercial-scale integrated production and use of renewable hydrogen. Hosted by the University of Texas at Austin (www.utexas.edu) and funded through the Energy Efficiency and Renewable Energy (EERE) program at the U.S. Department of Energy, the H2@Scale project involves nine industry partners, including Frontier Energy Inc. (San Ramon, Calif.; www.frontierenergy.com), GTI, Mitsubishi Heavy Industries, Shell, SoCalGas, Toyota Motor North American, Air Liquide and others.

The project represents a first-of-its-kind integration of commercial H_2 production, distribution, storage and use. Project partners will generate zero-carbon H_2 onsite via electrolysis (powered by solar and wind), and reformation of renewable natural gas from a Texas landfill. It is first time that both sources of renewable H_2 will be used in the same project, H2@Scale leaders say.

"Each of the individual hydrogen-related technologies already exists," explains Nico Bouwkamp, H2@Scale project manager at Frontier Energy. "But with this project, we are taking a systematic approach to tying everything together and demonstrating that the cost of H_2 energy can be lowered by connecting it to multiple sources and uses."

H_2 produced from the project will power a stationary fuel cell to provide clean, reliable power for the Texas Advanced Computing Center, and will also supply a H_2 station with zero-emissions fuel for a fleet of Toyota Mirai fuel-cell electric vehicles.

The H2@Scale project also involves a feasibility study at the Port of Houston that will investigate scaling up H_2 production and use. According to project statements, the study team will assess available resources, prospective H_2 users and delivery infrastructure, such as existing pipelines that supply H_2 to petroleum refineries along the Gulf Coast. The study will examine policies, regulations and economics to help industry partners develop a strategic action plan for policymakers that enables heavy-duty fuel cell transportation and energy systems.

domochemicals.com) has developed a new enhanced polymer material for the replacement of sintered carbon in submersible-pump thrust-bearings applications. Thermec S is designed to replace sintered carbons in submersible pumps that are exposed to continuous application temperatures of up to 200°C. Combining polyphenylene sulfide (PPS), glass, mineral fillers and lubricating additives, results in a synergistic effect that brings excellent abrasion resistance. This delivers a final product with better mechanical properties than sintered carbon samples. Due to its excellent processability, Thermec S is suitable for both injection molding and extrusion applications.

VOC SEPARATION

Evonik Industries AG (Essen, Germany; www.evonik.com) recently launched PuraMem VOC, a new membrane technology for the separation of volatile organic compounds (VOCs). This polymer-based membrane was developed for the separation of long-chain hydrocarbons from a natural gas or nitrogen mixture. The spiral-wound membrane module has been optimized for specialty applications, such as natural gas treatment, emission control in tank farms and other applications.

The new membrane technology functions on the basis of the different molecular sizes of the substances to be separated: the gas mixture streams through the membrane at a pressure of up to 80 bars; the larger VOC molecules pass through the membrane while the smaller gas molecules are retained. The company can adjust the selectivity to match a given application.

HYDROGENATION

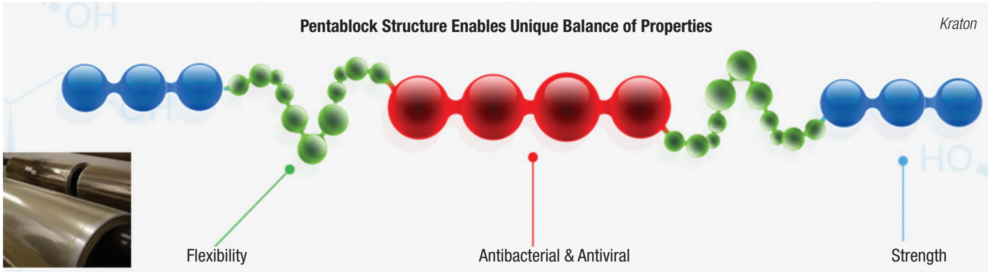
BASF SE (Ludwigshafen, Germany; www.basf.com) has introduced a new series of commercially proven alumina catalysts, which is now available with new performance features that can benefit selective-hydrogenation applications, such as first-stage pyrolysis gasoline (Pygas) or

(Continues on p. 7)

A fast-acting, durable self-disinfecting polymer

A patented polymer material developed by Kraton Corp. (Houston; www.kraton.com) has shown rapid antimicrobial capabilities with expected long-lasting self-disinfecting efficacy. Currently pursuing regulatory review in the U.S. and other select countries for use as an antimicrobial agent, Biaxam is a copolymer with an active sulfonated block that is permanently attached to the larger molecule, yielding a pentablock structure that balances antimicrobial activity with structural strength and flexibility (diagram). While there are other self-disinfecting products on the market, Biaxam is said to be the first to be tested against SARS-CoV-2 (the virus that causes COVID-19). It demonstrated long-lasting self-sterilizing effects. "There are many sterilizing products on the market that are based on zinc, copper and silver as the active ingredient. However, many of those products are not fast-acting, unlike Biaxam, which can inactivate 99.99% of microbes in as little as five minutes," explains Vijay Mhetar, senior vice president and chief technology officer at Kraton. Combining fast antimicrobial action with longer-lasting sanitizing sets Biaxam apart, says Mhetar, since most products currently on the market are only effective immediately, or require periodic treatment or reapplication.

Biaxam is manufactured using well-established styrenic-block copolymer chemistry, and Kraton is currently outlining its capabilities to scale up production once required regulatory approval is obtained. The company is also in discussion with a number of potential partners to explore applications for Biaxam. "Biaxam could be used in a variety of non-porous, non-food, high-contact surfaces, such as countertops, door handles, elevator buttons and public transportation surfaces, among others. It can be applied as a film, coating or replaceable peel-and-stick application," adds Mhetar.



A microwave-plasma process that efficiently makes hydrogen and acetylene

A new modular process based on microwave-plasma reactors aims to efficiently convert natural gas into acetylene and H_2 without combustion or CO_2 formation. Transform Materials LLC (Riviera Beach, Fla.; www.transformmaterials.com) has designed a reactor that overcomes some of the previous limitations of microwave-plasma-based methane processing, such as low single-pass conversion and low selectivity. "Our technology is singularly high in both conversion and selectivity. In addition, our process consumes approximately an order of magnitude less energy to process a fixed amount of methane," explains David Soane, Transform Materials CEO. Furthermore, the high single-pass conversion rates allow for a more compact reactor and overall simpler operations. "High-selectivity transformation into the desired coproducts of acetylene and hydrogen means that the requisite downstream separation process is straightforward," says Soane. He adds that the company has also made significant breakthroughs in removing minor amounts of byproduct impurities from the reactor effluent. "Our compact system favors distributed manufacturing. Future commercial plants can be installed where the natural gas feed exists and where there is local demand for the products," he continues.

The company has operated a fully integrated dual-reactor pilot plant with two 30-kW reactors, as well as a single-reactor 100-kW front-end demonstration system. Soane expects that future commercial installations will see multiplexing of 100-kW reactors coupled with appropriately sized back-end separation and purification units. The technology's modular nature means that plant capacity can be incrementally increased as demand rises. Transform Materials recently signed a technology-license agreement with Royal DSM N.V. (Heerlen, the Netherlands; www.dsm.com) that will enable DSM's Nutritional Products business to use biogas feedstock to make key ingredients. Transform Materials is also in talks with chemical manufacturers and other potential industry partners for further commercialization of its technology.

A novel, structural, carbon-negative cement

Magnesia cements have been around for thousands of years, and have been explored extensively over recent decades primarily because of their capacity to absorb CO_2 from the atmosphere at ambient temperatures. Until now, however, their use has been limited to rudimentary applications like cement block and non-load-bearing wall systems, because their formulations have been too corrosive to accommodate structural steel reinforcing agents, such as rebar. With support from Beton Consulting Engineers (Mendota Heights, MN; www.betonconsultingeng.com), MSB Global, Inc. (New York) has raised the pH of its reactive magnesia cement (RMC) to a level that meets the ASTM code compliance for a reinforcing steel agent, thereby making it suitable for structural, poured-in-place applications and enabling carbon negativity in as little as seven years.

It is well known that cement production accounts for about 8% of global CO_2 emissions. Approximately 90% of these emissions come from the production of clinker used as the binder in ordinary Portland cement (PC). PC relies on the use of calcium carbonate (limestone), which is calcinated at high temperatures in a cement kiln to produce lime (CaO), along with a release of CO_2 from the decarbonation of limestone. Finding an alternative to this limestone-based clinker has been the main hurdle to reducing the overall CO_2 emissions from cement production.

In contrast to Portland cement, the patented MSB formulation derives its main binder components from waste products of two other industries: granulated blast furnace slag (GBFS) and/or flyash, along with rejected brine from desalination processes or deep-water brackish wells. The waste brine is used to create magnesium oxide, along with other useful materials and combined with GBFS, pozzolans and other proprietary ingredients to provide the binder. The binder components in MSC are processed at temperatures of 400–700°C, compared to 1,450°C required for Portland cement. Upon the MSB concrete curing, the product will absorb CO_2 at the rate of 21.6 lb/yr per ton over its lifetime.

Beton's Mark Lukkarila and Kevin McDonald have demonstrated technical performance data, according to ASTM compliance standards for structural cement. MSB is currently looking for strategic partners to assist in bringing this technology to commercial scale.

selective hydrogenation of dienes in C4 olefin streams. This new series of Pd on spherically shaped E15x catalysts replaces the E14x series of Pd alumina catalysts that have been used commercially for over 30 years in selective hydrogenation applications. The new series of alumina-supported catalysts offers better activity and tolerance to poisons, such as sulfur due to higher Pd dispersion, says BASF. The catalysts are also very uniform in size and shape, which helps to prevent maldistribution of feed in fixed-bed reactor applications. This new series of selective hydrogenation catalysts is available with Pd contents ranging from 0.15 to 0.75% Pd.

BASF also introduced a new purified terephthalic acid (PTA) catalyst, CBA-250, which has a lower Pd content compared to the

(Continues on p. 8)

standard commercial PTA catalysts CBA-300 and CBA-400. The lower Pd content makes CBA-250 commercially attractive and easy to adopt, as it is formulated to be equivalent to standard commercial PTA catalysts.

CRYOGENIC ELECTROLYZERS

With their ability to produce emissions-free hydrogen, electrolyzers are hailed as the future of green energy, but there are still some high costs and risk associated with the catalytic and membrane elements used in traditional electrolyzer configurations. A new cryogenic electrolyzer developed by Clean Power Hydrogen Group Ltd. (CPH2; Doncaster, U.K.; www.cph2.com) has eliminated the need for catalysts and membranes in the production of hydrogen. The CPH2 system starts with a mixed gas stream that is cryogenically separated. "We make use of a highly efficient heat exchanger to recover the cold energy invested in the distillation of the oxygen from the mixed gas stream, and it is this process that renders the separation highly efficient," explains Nigel Williamson, CPH2 technology director. He also notes that CPH2's system adds safety benefits when compared to membrane-based systems, since membrane failure can lead to undetected mixing of gases, potentially resulting in catastrophic ignition. CPH2 has designed its systems for two hydrogen-purity output standards: 99.5% H_2 for standard applications; and 99.999% H_2 for fuel-cell applications. "Our gas leaves the system at 34 bars pressure, or, alternatively, may go on further down the Kelvin scale for liquefaction of the hydrogen. This makes our system highly cost-effective and efficient in such cryogenic storage and transportation applications," says Williamson.

So far, CPH2 has built small-scale proof-of-concept systems, but the company is currently manufacturing its first commercial-scale units for its joint venture with B9 Energy, which will implement green-hydrogen projects in Northern Ireland. "The technology is designed specifically for scalability and simplicity of construction. We are discussing the establishment of manufacturing plants in Australia, South Africa, Northern Ireland and Scotland, with a view to address the significant growth required to meet demand for the future," adds Williamson. The company is currently developing robotic-assembly capacity to improve manufacturing scaleup, while also working to further improve system efficiency and reduce costs.

RENEWABLE OXO PRODUCTS

Last month, Perstorp Holding AB (Malmö Perstorp, Sweden; www.perstorp.com) launched the first partly renewable carboxylic acids — 2-Ethylhexanoic Acid (EHA) Pro and Valeric Acid Pro. The 2-EHA Pro is based on 25% renewable raw materials, and Valeric Acid Pro contains 20% renewable content. The renewable material consists of biogas, which replaces natural gas.

2-EHA is used in plasticizers for polyvinyl butyral (PVB) film, synthetic lubricants, as a corrosion inhibitor in radiator coolants, siccatives and paint driers, and resins. Valeric acid is used for aviation lubricants, refrigeration lubricants and other esters for synthetic lubricants. ❑

New investment announced in platform technology for bio-based monomers

Zymergen (Emeryville, Calif.; www.zymergen.com) recently announced $300 million in new investments for the company's fermentation-based platform technology that generates novel bio-based monomers for specialty products applications. Combining synthetic biology with machine-learning-enhanced automated screening, Zymergen's technology has demonstrated the capability to identify and produce novel monomers and compounds via microbial fermentation.

The platform allows rapid scaling of economically viable production of biological molecules with performance attributes not attainable with incumbent materials. "We are aiming to fill as-yet unmet needs in specialty applications with a range of products based on renewable feedstocks that can be made at the same factory with modest capital investment, and with more environmentally sustainable processes," explains Zymergen's president Richard Pieters. Because these biologically derived molecules cannot be sourced from petroleum feedstock, the company can engineer unique property profiles that improve performance in ways petrochemical compounds cannot.

This opens a range of new application opportunities. Earlier this year, Zymergen, along with its development partner Sumitomo Chemical Co. (Tokyo, Japan; www.sumitomo-chem.co.jp), launched its first commercial product, known as Hyaline, a novel polyimide film for display screens in electronics applications. "Hyaline has unique optical transparency and other mechanical properties not attainable using existing materials, allowing us to push the boundaries of display technology, such as toward foldable touchscreens," explains Zach Serber, Zymergen co-founder and chief scientific officer. The company is also working on novel bio-based adhesives, pesticides and consumer-care insect repellent designed to achieve performance benefits over the existing options.

The company's automated screening system uses machine-learning algorithms to evaluate over 20,000 biological molecules, plus their derivatives, for properties that match specifications and market needs. Then, a small group of molecules predicted to have the correct properties is synthesized using genetically engineered microbial hosts. The bio-derived monomers are polymerized and further developed into the novel materials, such as the Hyaline film.

Acetylene-selective MOFs for ethylene purification

Ethylene is an important petrochemical, but it may contain traces of acetylene that can destroy the catalysts used in downstream processes. The separation of ethylene and acetylene is difficult, and the main method, distillation, is energy intensive. A potential alternative is the use of regenerable, inexpensive materials that selectively separate acetylene from ethylene.

Although such materials are not yet available, professor Dan Zhao and his team at the Dept. of Chemical and Biomolecular Engineering, the National University of Singapore (www.nus.edu.sg) have developed a suitable metal organic framework (MOF) for acetylene capture. By combining small MOF pore sizes with open nickel sites and sites for preferential acetylene binding, the team has created a Ni-MOF called Ni(3)(pzdc)(2)(7Hade)(2) that can meet the demands of selectivity and robustness. The team has also adjusted the pore sizes of the MOF to allow entry only for very small gas molecules and filled the pore walls with chemical groups that would attract acetylene over ethylene.

According to the team, the Ni-MOF purified an ethylene stream by a factor of a thousand and maintained its high selectivity across a range of pressures and regeneration cycles. The Ni-MOF can be prepared in a standard hydrothermal procedure. ■

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Plant Watch

Solvay inaugurates second bio-based solvent plant in Brazil

October 15, 2020 — Solvay S.A. (Brussels, Belgium; www.solvay.com) inaugurated its second manufacturing plant in Brazil for its bio-based solvent marketed under the name Augeo. Installed in the company's industrial complex in Paulinia, the new plant raises Augeo production capacity from 6,000 metric tons per year (m.t./yr) up to 20,000 m.t./yr.

Air Liquide to invest €40 million to build ASU in Poland

October 13, 2020 — Air Liquide (Paris, France; www.airliquide.com) will invest around €40 million in the construction of a new air-separation unit (ASU) at the Głogów, Poland site of KGHM Polska Miedz, one of the largest producers of copper and silver in the world. This new investment will add a capacity of more than 1,200 ton/d of oxygen to the Głogów site, which will bring Air Liquide's total oxygen production capacity at this location to nearly 2,800 ton/d.

Wacker to expand VAE production in Nanjing

October 13, 2020 — Wacker Chemie AG (Munich, Germany; www.wacker.com) is investing around $100 million to add a reactor for vinyl-acetate-ethylene (VAE) copolymer dispersions and a spray dryer for VAE-based dispersible polymer powders at its site in Nanjing, China. The reactor and spray dryer are scheduled to come onstream in 2022. The two plants, when completed, will be the largest of their kind in the world.

BASF to increase production of synthetic ester base stocks in Jinshan, China

October 12, 2020 — BASF SE (Ludwigshafen, Germany; www.basf.com) will almost double the production capacity for its synthetic ester base stocks at its site in Jinshan, China. The capacity expansion is expected to reach completion by the second half of 2022.

Tatneft to construct *n*-butane processing plant

October 12, 2020 — PJSC Tatneft (Almetyevsk, Russia; www.tatneft.ru) plans to construct a new processing unit for *n*-butane, which will have a production capacity of 50,000 m.t./yr. Located at the company's Minnibayevo gas processing plant, the new unit is scheduled to be commissioned in 2023.

Messer to build CO_2-recovery unit at Vertex Bioenergy site in France

October 8, 2020 — Messer Group GmbH (Bad Soden, Germany; www.messer.com) will build and operate a second CO_2-recovery unit at Vertex Bioenergy's bioethanol production site in Lacq, France. Vertex Bioenergy will supply Messer with 130,000 m.t./yr of raw CO_2 for the two recovery units. This new unit, which represents an investment of €11.3 million, is scheduled for startup in July 2022. It will allow Messer to double its CO_2 production capacities from this site.

Covestro launches new polycarbonate films line in Thailand

October 8, 2020 — Covestro AG (Leverkusen, Germany; www.covestro.com) has launched a new production line for polycarbonate films in the Map Ta Phut Industrial Estate in Thailand. The total investment of over €100 million also includes an expansion of the associated infrastructure and logistics to shorten delivery times.

AkzoNobel to build new powder-coatings plant in Taiwan

October 5, 2020 — AkzoNobel (Amsterdam, the Netherlands; www.akzonobel.com) is building a new powder-coatings plant in Chungli, Taiwan. The new plant, which represents a €20-million investment, is expected to start operating in the third quarter of 2021.

OQ Chemicals completes capacity expansion for isononanoic acid

October 1, 2020 — OQ Chemicals (Monheim am Rhein, Germany; chemicals.oq.com) has completed an expansion project at its Oberhausen, Germany site, resulting in a 30% increase in its global production capacity for isononanoic acid. Isononanoic acid is a key ingredient in synthetic polyol-ester-based lubricants for the refrigeration industry.

Nippon Shokubai to construct new battery-electrolyte manufacturing plant

October 1, 2020 — Nippon Shokubai Ltd. (Osaka, Japan; www.shokubai.co.jp) plans to build an enhanced production plant for the electrolyte lithium bis(fluorosulfonyl) imide (LiFSI) for lithium-ion batteries. The company's current production capacity for LiFSI is 300 m.t./yr, and the new facility will add around 2,000 m.t./yr of additional LiFSI capacity.

Siemens to build large CO_2-free hydrogen plant in southern Germany

September 25, 2020 — Siemens AG (Munich, Germany; www.siemens.com) and WUN H2 GmbH plan to build one of the largest hydrogen production plants in Germany. The electrolysis plant from Siemens Energy will have the capacity to produce over 900 m.t./yr of hydrogen in its first phase. When fully expanded, it will be able to supply up to 2,000 m.t./yr of hydrogen. Commissioning of the plant is expected at the end of 2021.

Mergers & Acquisitions

Mitsubishi Chemical to sell its polymer-flocculant sales business

October 13, 2020 — Mitsubishi Chemical Corp. (Tokyo, Japan; www.m-chemical.co.jp) will transfer its polymer-flocculant sales business to Tokyo-based firms MT AquaPolymer, Inc. (MTAP) and Hymo Corp. The transfer to MTAP involves anionic, cationic and amphoteric flocculants and organic coagulants. The transfer to Hymo involves *n*-vinylformamide and polyvinylamine, as well as liquid polymers, defoaming agents and more.

Celanese completes Polyplastics sale

October 12, 2020 — Celanese Corp. (Dallas, Tex.; www.celanese.com) completed the sale of its 45% equity investment in the Polyplastics joint venture to Daicel Corp. (Tokyo, Japan; www.daicel.com) for $1.575 billion.

Vopak and Chandra Asri form infrastructure JV

October 6, 2020 — PT Chandra Asri Petrochemical Tbk (Jakarta, Indonesia; www.chandra-asri.com) and Royal Vopak (Rotterdam, the Netherlands; www.vopak.com) intend to set up a joint venture (JV) for collaboration related to industrial-infrastructure business ventures in Cilegon, Indonesia.

LyondellBasell and Sasol form integrated polyethylene JV

October 2, 2020 — LyondellBasell Industries N.V. (Rotterdam, the Netherlands; www.lyondellbasell.com) and Sasol Ltd. (Johannesburg, South Africa; www.sasol.com) agreed to form a 50/50 JV, through which LyondellBasell will acquire 50% of Sasol's Lake Charles ethane cracker, low and linear-low-density polyethylene plants and associated infrastructure, for a total consideration of $2 billion. The JV will operate under the name Louisiana Integrated Polyethylene JV, LLC.

BASF closes divestiture of its Construction Chemicals business

October 1, 2020 — BASF closed the divestiture of its Construction Chemicals business to an affiliate of global private equity firm Lone Star. The purchase price is €3.17 billion. The former BASF Construction Chemicals business now forms the MBCC Group, headquartered in Mannheim, Germany.

Covestro to acquire DSM's Resins & Functional Materials business

September 30, 2020 — Royal DSM N.V. (Geleen, the Netherlands; www.dsm.com) agreed to sell its Resins & Functional Materials and associated businesses (RFM) to Covestro for €1.6 billion. The transaction includes all of DSM's RFM businesses, including DSM Niaga, DSM Additive Manufacturing and the coatings activities of DSM Advanced Solar.

Tokuyama and Formosa Plastics form IPA joint venture

September 28, 2020 — Tokuyama Corp. (Tokyo, Japan; www.tokuyama.co.jp) will form a 50-50 JV in Taiwan with Formosa Plastics Corp. (Taipei, Taiwan; www.fpc.com.tw) for selling high-purity isopropyl alcohol (IPA). Located in in Kaohsiung City, Taiwan, the JV will be called Formosa Tokuyama Advanced Chemicals Co. ■

Mary Page Bailey

Mitigate Dust Hazards With Good Equipment and System Design

By carefully considering equipment and plant design in processes involving powdered materials, fugitive dust issues can be reduced significantly

Chuck Kerwin and Gus Carrington
AZO Inc.

Powdered ingredients that unintentionally leak from equipment in a manufacturing plant are known as fugitive dust. The risks associated with fugitive dust are very real. The three major risk factors are: 1) combustion risk 2) operator exposure (inhalation and contact) risk and 3) product hygiene risk. It is difficult, if not impossible, to eliminate all dust from a manufacturing plant, but controlling fugitive dust starts with equipment design. Minimizing dust in and around bulk-material-handling systems is most effective when less dust is allowed to escape from your material-handling system. This article provides information on design strategies and considerations for building effective dust containment into new equipment. This approach may increase upfront equipment cost, but will lower operating costs and avoid dust-issue headaches later.

FIGURE 1. All components of the solids-handling system, from bulk bags, like those shown here, to feeding and conveying, should be considered in a dust-mitigation strategy

Dust reduction by design

The importance of plant housekeeping should not be overlooked in controlling dust, but there is more to it. Automated powder-handling systems are made up of multiple components, working in concert, to move ingredients from storage containers to processing equipment. Features to control fugitive dust can be designed into each component that make up the system. These components include conveying, filtering, dosing, loading and unloading. An initial focus on these components, followed by the entire ingredient-handling system, can go a long way toward reducing fugitive dust and lost material. For example, integrated designs have self-cleaning filters that return collected dust back into the production process. In contrast, centralized dust control systems collect dust in a central baghouse. This dust is lost from production, because it becomes contaminated with all the other dust in the collection point. Centralized dust control is effective for containing fugitive dust, but has higher operating costs due to this lost material. Fugitive dust control is no easy feat since the whole is only as good as the sum of each component in a material handling system (Figure 1).

Combustion risk

Most powdered material has some combustion threat, so each ingredient in your plant should be identified and analyzed for material-specific risks (Figure 2). Combustion requires three elements: heat, fuel and oxygen. Airborne dust significantly increases the combustion risk of any powder because this dust cloud already includes two sides of the fire triangle, fuel and oxygen. Only heat, or specifically, an ignition source, is needed for dust combustion.

Many common ingredients pose significant combustion threats. Sugar provides an illustrative example. There have been many high-profile industrial accidents, involving sugar, attributable to poor material-handling practices. One noteworthy event was the destruction of Imperial Sugar's refinery in Savannah (Port Wentworth), Georgia in 2008. This accident started with a relatively small sugar dust explosion, which triggered a chain reaction of explosions and shock waves, each causing more fugitive dust to become airborne and feed the chain reaction. The resulting fire killed 11 employees and took an entire week for firefighters to extinguish.

Each powder has its own properties and characteristics. A dust hazards analysis (DHA) in accordance with National Fire Protection Association (NFPA; Quincy, Mass.; www.nfpa.org) standards is a good way to identify potential risks around your factory. NFPA is an international nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical

and related hazards. Focus on DHAs has increased lately due to several pending compliance deadlines. While not an enforcement agency, the NFPA has set two specific testing deadlines. The first deadline, which applies to compliance with NFPA 652 industries (which include: chemical, food, fertilizer, tobacco, plastics, rubber, pesticides, pharmaceuticals, rubber, wood, dyes and metals) was September 7, 2020. The second deadline applies to NFPA 61 (industries doing primarily agricultural processing) has a deadline of January 1, 2022. The authors encourage all manufacturers to be aware of their resident dust hazards and to take appropriate safety precautions to protect both people and property.

Component design tips

Once material challenges are identified, a plan of action should be developed to mitigate the risks associated with fugitive dust. A review of known problem areas often leads to a classic management decision — replace or repair. While capital budgets are always tight, trying to repair worn out or poorly designed equipment often treats the fugitive dust symptoms rather than the root cause. Other factors to consider in deciding to replace or repair equipment include capacity constraints, the amount of manual labor required and the age of the control system. If capital budgets allows for replacement, then new equipment design becomes critical.

As stated at the outset, good dust control starts with equipment design, but the entire system design as a whole should also be considered. Bulk powder material-handling systems usually involve multiple ingredients moving through a series of single-function components that operate together in a fully integrated system. The following provides design tips to control fugitive dust in components commonly found in material-handling systems, including conveying, filters, feeders, bulk unloaders and bag dumps, as well as considerations for integrated system design and plant layout.

Conveying. There are two basic ways to use air to move powdered material through pipes — pressure and vacuum conveying. Pressure conveying uses air at a higher pressure than ambient pressure, to "blow" powders through pipes. Vacuum conveying uses air at a lower pressure than ambient pressure, to "suck" powders through pipes. Both technologies have their place in the material-handling world, but vacuum systems have some particular benefits with regard to fugitive dust control. Since vacuum conveying operates under negative pressure, leaks in the conveying line will draw air into the conveying system. While such a leak is an operating inefficiency, ingredient dust remains in the system and does not create fugitive dust. A leak in a pressurized conveying system does the opposite; conveying air will be blown out of the conveying system, and with it, fugitive dust. Leaks in pressure-conveying systems can create extremely dusty work environments if not corrected. For this reason, vacuum conveying is inherently a cleaner way to move bulk powders as compared to pressure conveying.

Material conveying systems moving ingredients often have long conveying distances, sometimes through inaccessible areas. This can make leak detection a tedious and time-consuming exercise with pressure-conveying systems. Leaks can be easily missed if they are located in a hard-to-reach areas or hidden behind other equipment. This is of special concern when conveying toxic or noxious materials. Products that could be harmful to operators are best conveyed by vacuum systems, because leaks do not create fugitive dust.

Filters. Filters play a critical role in material-handling systems and are critical for effective dust control. Filters are used to separate ingredient dust from conveying air exiting the system. Filters are a critical safety component to control dust emissions from bulk-material-handling equipment. Commonly located at the receiving hopper at the end of a conveying line, filters have several functions: cleaning the conveyed air, preventing overpressuring the hopper, and recycling the ingredient dust that was suspended in the air flow. The filter strips dust out of the conveying air so it can be vented into the plant or to the environment through an exterior opening. Regular preventive maintenance of the filters keeps the filters working and promotes good plant housekeeping.

Integrated filters are installed in the receiving hopper and include self-cleaning features to reduce filter maintenance and lost material. One self-cleaning filter mechanism uses pressurized air to pulse the filter media, causing dust on the dirty side of the filter to loosen and fall down to join the rest of the ingredients in the hopper. This process not only cleans the filter, it also minimizes ingredient loss. Filters installed outside of the receiving hopper and connected to a centralized dust collection perform the same cleaning function, but cannot recycle product dust.

Filter cleaning and change-out frequency is product-specific, but critical nonetheless. Dust accumulation on the filter limits the effective filter surface area and ultimately clogs the filter media. Self-cleaning filters will extend filter life, but frequent inspection should still be performed to ensure there are no tears or splits in the filter. Particle size also affects the frequency of bag changes. There is wide variety of filter media and open area available to meet any manufacturing specification. Most filters are made of polyester, but there are other materials and filter features available. Anti-static filters reduce static electricity created by filter pulse cleaning. A PTFE (polytetrafluoroethylene)

While capital budgets are always tight, trying to repair worn out or poorly designed equipment often treats the fugitive dust symptoms rather than the root cause.

FIGURE 2. Fugitive dust can lead to explosions, so each material should be analyzed for combustion risk, and materials-handling processes should be examined for the root cause of the dust escape

filter is more effective because it has a higher micron-retention rate. PTFE filters are also very effective when dealing with sticky material as its PTFE coating allows built up material to slide off more easily than common polyester filters.

Dosing. Dosing, also known as feeding, is the means by which consistent streams of ingredients are introduced into a process at a certain rate. Whether dosing into an extruder, a conveying line or loss-in-weight/gain-in-weight feeders, there are many concerns related to measuring accuracy, but there are also dust leakage issues to be aware of. Dust does not generally accumulate in the feeder itself; the real dust issues are further downstream where the material is discharged from the feeder. If the feeder discharges into a dust-tight closed container, then this risk is easily mitigated. Many feeders, however, feed into open hoppers or scales. In this case, a connection to a dust-control system is highly recommended. In most cases, this would be a centralized dust-control system.

A secondary concern to avoid excessive dust around feeders is making sure they are properly sealed. A feeder is a closed-component, so visible dust generally indicates a worn seal. There are three areas in a feeder that require regular seal inspection. These areas are the inlet flange, the main drive and the discharge. If you spot dust around a feeder, chances are there is a bad seal in one of these locations. Regularly scheduled preventive maintenance for these seals in the feeder is recommended. If one of the seals is found to be worn, replacing all the seals and gaskets at the same time is likely the best course of action. It costs a little more, but the rebuilt feeder operates like new and will ensure trouble-free performance when put back in production.

Bulk-bag unloading. Bulk-bag unloading involves emptying big bags, super sacks, bulk bags (all describe a 2,000-lb cloth sack) as efficiently and cleanly as possible (Figure 1). Bulk bag unloaders are common in all industries and just about every manufacturing plant has at least one. Generally, bulk-bag unloading is very dusty, but it doesn't have to be. Fugitive dust can be released from two different sources: poor equipment design and operator errors. Let's start with design first. There is a wide choice of bulk bag unloaders on the market and generally you get what you pay for. Higher-price bulk-bag unloaders usually include better dust management features. Such features include: active dust control when connecting or disconnecting bags; empty bag dust control; bag connections that are dust-tight; and outlet spout control.

With these dust-control features in mind, there are four basic actions to control fugitive dust when unloading bulk bags. First, each full big bag should be properly connected to the unloading mechanism. The bag connection should be tight, properly

sealed and user friendly (no hand tools required). Second, the connection should be made in a closed hopper that has its own, built-in dust-control system. As the product begins to flow from the bag into the hopper, the air displaced from the hopper should be vented to a dust-control system. Lastly, the empty bag should be collapsed while in the frame and still attached to the dust-control system. An empty big bag usually has residual dust in it and is often the primary source of dust around big bag unloaders.

A bulk bag unloader's bag connection is particularly effective if it includes a cover. This connection unit is sometimes referred to as a big bag adapter (BBA). With a cover, the BBA can be sealed once a full bag is connected or an empty bag disconnected. The flow of product out of the big bag will create a rush of displaced air out of the hopper. This displaced air includes a lot of dust and needs to be contained inside the hopper. A vent stub, built into the hopper, is the most effective way to prevent fugitive dust from escaping the unloader. The same vent is also used to capture residual dust before disconnecting an empty big bag.

Operator errors can also generate a lot of fugitive dust around big bag unloaders. Operators should be regularly trained and monitored to ensure they follow procedures and use the dust control features built into the big bag unloaders. Care should also be taken by operators as they remove empty bulk bags from the big bag unloader. Not all materials flow freely from big bags and a significant amount of dust can be retained in the fabric folds of an empty bag. To control this residual dust, the bag must be deflated while connected to the BBA and its dust-control system. The operator should also manually flex the bag and spout before disconnecting the bag. The empty bag is now ready to be removed from the big bag hoist and transported away from the work area. Skilled operators that follow proper procedures can significantly reduce the release of fugitive dust.

As a last point to mention about big bags, don't overlook fugitive dust created by tears or rips in fabric big bags caused by careless handling and storage. Careless fork truck drivers can easily rip or tear super sacks when moving them from the warehouse to the big bag unloading station. Big bags can be ripped by brushing against sharp edges or punctured by lift truck forks. Access to big bag unloader stations should be considered in plant layouts to minimize super sack damage.

Bag dumps. Bag dumps are used to manually unload raw materials stored in cloth or paper sacks, normally between 50 and 100 pounds. This dumping process has dust-control issues similar to those of big-bag unloading mentioned earlier. The operator must cut the sacks open and dump the contents into the bag dump. There are two types of bag dumps: dedicated bag dumps (for storage) and pass-through receivers (for conveying). This cutting and dumping process can generate a lot of dust, exposing the operator and work environment to fugitive dust. This dust can be controlled by either an integrated dust collector, which is built into each bag dump, or a centralized dust collector, where the bag dump is connected to a common dust-collection system.

As mentioned previously, an integrated dust collector, built into the bag dump, has the advantage of recycling the dust back into the hopper; all the dust that it is collected in the hopper stays with the product. A common dust-control system will control dust, but will lose material to production. Either dust-control system should be automatically activated when the bag dump door is opened by the operator. That way, the operator does not have to remember to turn on the dust-control system. When the door is opened, the fan activates and draws air into the hopper from around the operator. As the operator dumps bags, the product dust is drawn away from the operator into the hopper. With an integrated dust control system, closing the bag-dump door automatically pulses the filter with a blast of air, which releases captured dust on the filter and drops it into the hopper.

Lastly, be sure to include a plan to deal with the empty bags. These bags, while empty, are usually full of residual dust. Improper bag disposal can produce a giant cloud of fugitive dust, covering both the operator and the work area. Look for bag dumps that include bag-disposal systems that accumulate empty bags into a sealed trash bag without releasing fugitive dust. While costlier, this feature will pay for itself many times over.

Flex sleeves. A flex sleeve is a flexible section of plastic conduit often used in conveying lines that aids the flow of product through the conveying system. The flexible conduit is especially effective when dealing with materials that are sticky, pack easily or have a high fat content. The flex sleeve is connected to the metal conveying lines with a pipe clamp at each end of the sleeve. The sleeve's flexibility allows it to vibrate and move, helping to dislodge built up product inside the flex sleeve. This movement, while effective for dislodging material, requires regular maintenance to ensure the clamp connections remain tight and dust-free. This is especially important for pressurized-conveying systems. Plant maintenance should also check flex sleeves for rips or tears, because constant movement will fatigue the plastic sleeve. Flex sleeves should only be installed in areas that are both visible and accessible.

Controlling fugitive dust is challenging, but equipment designed with integrated dust-control features can give operators the tools they need to do their jobs safely and cleanly. ■

Edited by Scott Jenkins

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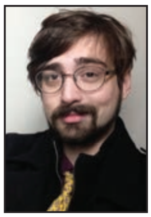

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Fans, Blowers, Compressors

Automatic lubricators increase reliability of rotating equipment

This company's Shield lubricators (photo) extend the life of rolling element bearings in fans, blowers, electric motors, pumps, conveyors and other rotating equipment by delivering a consistent, precise supply of lubricant. These automatic lubricators can be installed at any bearing-lubrication point and set for a discharge period of 1 to 12 months. Once activated, Shield lubricators discharge fresh lubricant into the lubrication point, while the equipment is running. The simple setup and automatic discharge significantly reduce the time required to lubricate equipment, eliminate the need for continuous monitoring by facility personnel, and reduce safety risks. Shield lubricators are available as gas-driven or electromechanically driven systems, in a variety of lubrication volumes and more than 400 lubrication types. — *Cook Compression, Houston*
www.cookcompression.com

PFD fan line has higher speeds and larger sizes

This manufacturer recently increased the capacity of its size 3000, and added two new larger sizes for its Packaged Forced Draft (PFD) fan line. The size 3000 can now reach static pressures up to 58 in. The two new sizes — size 4900 and size 5414 — increase the capacity to 120,000 ft^3/min. These new sizes offer users pre-engineered, heavy-duty fans, without the longer lead times and higher costs normally associated with custom-made fans. — *Chicago Blower Corp., Glendale Heights, Ill.*
www.chicagoblower.com

Portable blowers supplement air supply when needed

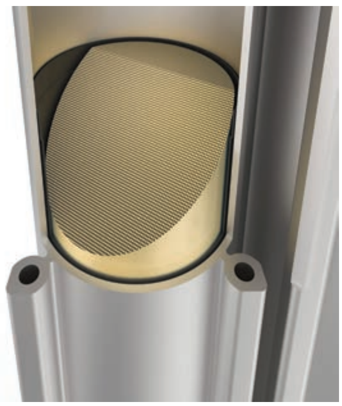
Whether in confined spaces or large open areas, portable purging fans (photo) can extract any residual toxic air and safely direct it into a capture hood for safe disposal or treatment. With chemical toxicity often undetectable by the human senses, these portable units — available in either electric-drive motors or gasoline-powered — serve those industries dependent on fresh air supply to safeguard employees in workshops, worksites or even in remote and semi-remote locations. Apart from removing toxic fumes, this equipment is manufactured for general applicability in supplying clean air, as an air-pressure supply source, as a ventilator in confined space, and for general air-flow maintenance duties. Electric-powered units have a motor speed of 2,880 rpm and are available in two diameters, 160 or 200 mm. The 160-mm dia. versions have 0.55-kW power operations capable of moving 450 L/s of air. All 200-mm dia. models have 1.50-kW power and move 890 L/s of air. — *Fanquip, Singleton, NSW, Australia*
www.fanquip.com.au

Introducing the first-ever solid desiccant for compressed air

Cerades (photo) is a patented desiccant for compressed-air dryers introduced earlier this year. As the first-ever solid, ceramic desiccant, Cerades is said to offer operators of compressed air significantly better air quality, lowering pressure drops by up to 70%, with improved energy efficiency, lower service costs and improved environmental benefits. The vibration-resistant Cerades desiccant enables trouble-free installation and continuous operation in rigorous applications. Cerades is designed to deliver significant savings by streamlining the flow of the compressed air through a desiccant dryer. Compressed air flows directly through Cerades' straight-structured tubes, as opposed to pushing its way through the thousands of separate beads found in loose desiccant. This no-resistance flow means the air experiences a smaller pressure drop as it travels through the dryer, significantly lowering the energy cost of operation. Cerades desiccant lasts, on average, a minimum of two years longer than traditional desiccant, and under normal operating conditions you would only change Cerades desiccant every seven years. — *Atlas Copco Compressors LLC, Rock Hill, S.C.*
www.atlascopco.com/air-usa

Cook Compression

Fanquip



Atlas Copco Compressors

Kaeser Compressors

Lone Star Blower

Dryer uses latent thermal-heat storage for energy efficiency

The new TF series (photo), with four models from 550 to 1,130 std. ft^3/min, integrates this company's Secopack LS latent heat thermal-storage system that delivers consistent dew-point control and energy efficiency under varying load conditions. Secopack LS contains a phase-change material (PCM) that stores thermal energy as it cycles from a solid to a liquid state, greatly enhancing energy efficiency. The PCM module is 98% denser than conventional storage media. This, combined with topside air exhaust, creates a smaller overall footprint for the dryer, says the company. TF dryers also feature a variable-speed radial fan design that improves cooling and enables ducting and heat recovery. A dedicated fan in the electrical cabinet and optional water-cooling allow operation in high-heat environments without loss of drying capacity. — *Kaeser Compressors, Inc., Fredericksburg, Va.*
www.kaeser.com

A wide range of flowrates covered by these blowers

This company manufactures API 672 integrally geared turbo blowers and multistage centrifugal-type blowers covering a range from 500 to 90,000 ft^3/min for air, gas, pressure and vacuum. The LS Series multistage turbo blowers (photo) are available in sizes from 30 to 3,000 hp, handling pressures from 2 to 25 psig and flowrates of 300 to 45,000 std. ft^3/min for air or gas. The multistage turbo blower is designed to operate with variable frequency drive control. Each model can be built from one to ten stages, and direct coupling means no gears or belts are required. Many impeller designs can be mixed to maximize efficiency. Compared to alternatives, the blower is said to cover a 30% greater pressure range and is 5 to 7% more efficient. Control options are available to meet any area classification (Class 1, Div. 1 to Zone 0 or Atex certified). — *Lone Star Blower, Inc., Houston*
www.lonestarblower.com

A new compressor series for high-pressure requirements

The air-cooled Orkan series (photo) comprises oil-lubricated piston compressors and gas compressors of up to 110 kW for final pressures of up to 500 barg. Booster solutions with inlet pressures of up to 16 barg are also covered. The Orkan series is based on a modular system, and various designs are ready for handling special requirements. There are hermetically gas-tight and explosion-proof versions for helium, natural gas and hydrogen. In the hermetically gas-tight compressors, the company uses a new type of magnet coupling for the first time. It not only guarantees absolute gas-tightness but is also extremely low-maintenance and operates with maximum reliability. Another novelty of the Orkan series is the innovative cooling concept. The new CubeCooler enables re-cooling temperatures that are more than 30% lower than those of conventional cooler configurations, the company says. To achieve such a high cooling capacity, the coolers are arranged radially around the combined fan and flywheel. This cooling concept has already proven itself in the manufacturer's medium-pressure Breeze series. — *J.P. Sauer & Sohn Maschinenbau GmbH, Kiel, Germany*

www.sauercompressors.com

J.P. Sauer & Sohn Machinenbau

An intermediate-sized blower fills a gap in this product range

With the new size within the Delta Blower Generation 5 (photo), the previous volume jumps of 5,400 and 7,900 m^3/h are now complemented with an intermediate size of 6,300 m^3/h at a nominal diameter of DN 250 and a pressure range of up to 1,000 mbar. Offering a wide range of applications for the oil-free transport of air and neutral gases, the Generation 5 Delta Blower assemblies highlight the more than 150 years of development know-how of this company. The powerful, robust positive-displacement blowers are highly reliable in continuous operation. They are easy to handle and designed to produce a low level of noise. — *Aerzener Maschinenfabrik GmbH, Aerzen, Germany*

www.aerzen.com

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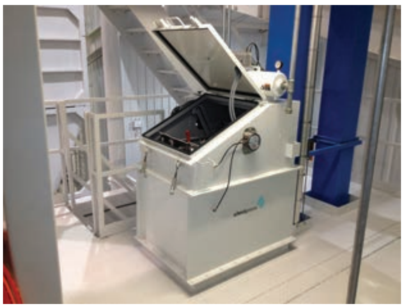

Schenck Process

Siemens

Industry's first 'four-in-one' compact flowmeter

The new Rosemount 8800 Quad Vortex flowmeter (photo) is specifically designed to meet stringent safety standards in environments and applications that require safety instrumented systems (SIS). The flowmeter is said to be the first in the industry with quadruple sensors and transmitters to meet safety integrity level (SIL) requirements. Consisting of multiple independent sensors in an all-welded meter body, the compact device provides built-in redundancies for added safety without introducing intentional leak points. The meter reduces piping needs threefold by eliminating the additional flanges and pipe runs required for the installation of multiple flowmeters in a redundant flow-measurement installation. With the ability to meet measurement challenges where space is limited, and safety is crucial, the Rosemount 8800 Quad Vortex flowmeter accomplishes the same task as four separate meters, without needing impulse lines that might clog. — *Emerson, St. Louis, Mo.*
www.emerson.com

On-site N_2 supplied by these membrane-based systems

The new NGMs 1–3 range of nitrogen generators (photo) features membrane technology and offers a highly efficient, compact and simple on-site solution for low-flow N_2 requirements, with the added benefits of minimal maintenance and operational costs. There are three models in the new NGMs range, and each can be wall-mounted to save space in small facilities. The NGMs generators boast a fast startup time, taking only a few seconds to produce nitrogen at the outlet. This results in maximum uptime and a continuous availability of N_2. The generators are supplied as an all-in-one, integrated package, complete with filters. Fitted with pressure gages to ensure accurate system monitoring at all times, the ready-to-use units are housed in a fully enclosed protective canopy. No specialist installation or commissioning is required — only a supply of dry compressed air. — *Atlas Copco Compressors LLC, Rock Hill, S.C.*
www.atlascopco.com/air-usa

An efficient dust collector with a small footprint

The Mac SpaceSaver dust collector (photo) is said to be up to 75% smaller than traditional dust collectors, offering a superior cleaning mechanism and long-lasting, leak-free cartridges. With a footprint as small as 27 × 38 in.^{2}, the Mac SpaceSaver is suitable for applications with limited space requirements in terms of both cross-section and overall height, as well as in areas of the plant that are not connected to central dust-collection systems. Many cartridge styles are available to best fit the application, with sizes ranging from 2 to 48 cartridges per collector. The Mac SpaceSaver uses patented directed airflow to thoroughly pulse the cartridges. This directed airflow extends cartridge life and uses compressed air more efficiently than competitive models. Complete tool-free cartridge changeout and a unique blowpipe configuration simplify maintenance. Because users can change the cartridge without having to enter the collector, there are no confined-space entry issues. — *Schenck Process LLC, Kansas City, Mo.*
www.schenckprocess.com/us

New 80-GHz compact radar transmitters for level

Two new models have been added to this company's Sitrans LR100 series of 80-GHz radar transmitters (photo). These high-frequency, compact transmitters deliver reliable measurements even in challenging environments. Sitrans LR140 features 4–20-mA simplicity and is configured via Bluetooth wireless technology and the Sitrans mobile IQ App. Sitrans LR150 offers a four-button user interface on an optional human-machine interface (HMI) for configuration or monitoring. Configuration is also available via Bluetooth wireless technology and the Sitrans mobile IQ App or remotely with 4–20-mA HART using Simatic PDM. The easy-to-use Quick Start Wizard will have the transmitter operational in minutes. Custom microchip technology delivers fast response and extremely high sensitivity to detect even the weakest of signals. — *Siemens AG, Munich, Germany*
www.siemens.com

A non-metallic, curved-top motor-disconnect switch

The new CDS Series of non-metallic, curved-top motor-disconnect switches (photo) features a curved profile to eliminate standing water and minimize contaminant buildup in food processing and cleanroom operating environments. In addition to its curved profile, the CDS Series features a chemically resistant thermoplastic enclosure with UL Type 4X and IP69K ratings, making it resistant to frequent high-pressure washdown. Its highly visible handle is lockout-tagout compliant. The CDS Series is NSF-certified for food processing areas. Other features include: laser marking for permanent identification; captive stainless-steel cover screws; poured-in-place seamless gasket; standard early-break auxiliary contacts; and more. — *Mennekes Elektrotechnik GmbH & Co. KG, Kirchhundem, Germany*
www.mennekes.com

Service and support expanded with this new portal

My Tech Support Portal (photo) provides continuous access to online resources and tools to perform immediate self-service and to manage their support and service cases. In addition to phone support, the My Tech Support Portal offers 24/7 access to a growing knowledge base on this company's instrumentation and applications, along with the ability to create and manage support and service cases online. Users benefit from a growing database of knowledge and extensive service expertise from actual support cases. My Tech Support provides immediate access to articles on diagnostics and troubleshooting, and on product and application know-how, such as service operations. Users simply log in, describe the issue, and access the knowledge database for an immediate solution. — *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com

Mennekes Elektrotechnik


Endress+Hauser

ECOM Instruments

Thermon Group Holdings

Toshiba America

Pfeiffer Vacuum

A new smartphone for hazardous areas

Last month, this company introduced the new generation of its intrinsically safe 4G/LTE Android smartphone Smart-Ex 02 (photo). With a large 5-in. display and smart ergonomics, the Smart-Ex 02 is said to be the most advanced explosion-proof smartphone for Zone 1/21 and Div. 1 areas. Equipped with the Android 9 operating system, the smartphone is fast and secure. It simplifies communication between employees, the control center and backend systems. The Smart-Ex 02 supports 21 different LTE frequency bands and is delivered simlock-free. Global Ex and approval certifications enable worldwide use and global rollouts. Smart-Ex 02 is also AT&T approved and network ready. — *ECOM Instruments GmbH, a Pepperl+Fuchs brand, Assamstadt, Germany*

www.ecom-ex.com

Comprehensive connectivity and monitoring for heat-trace systems

Genesis Network (photo) is a new system that provides site-wide operational awareness and supervisory control of heat-trace systems. Users can easily monitor, maintain and troubleshoot even the largest heat-trace systems that may include over 10,000 heat-trace circuits. The Genesis Network connects heat-trace controllers with the control room using wireless communications, presenting alarms, history and operational data via a browser-based interface accessible from any network-connected computer or mobile tablet. Utilizing an adaptive, self-healing wireless mesh network and event-driven communications, users experience realtime status reporting and responsive control of their heat-trace systems. The following new components work together to form the Genesis Network: Genesis Server, an on-premises or cloud-deployable server; Genesis Gateway, a communications device between the server and wireless mesh; and Genesis Bridge, a communications device between the mesh and heat-trace controllers. — *Thermon Group Holdings, Inc., Austin, Tex.*

www.thermon.com

An integrated IoT software for water-treatment facilities

This company is launching the IoT Solution Pack software application (photo) for water and wastewater treatment plants. IoT Solution Pack delivers remote monitoring, visualization, analytics and data-collection capabilities. It can be quickly deployed to connect a variety of devices to reduce costs and improve efficiency and control. Plants can drive near-realtime visualization and optimization by connecting equipment and shifting process data and applications to the cloud through sensors, adapters and gateways. Setup is easy, using predefined templates that enable quick configuration of authorized gateways. Once deployed, the software enables operators to quickly gain facility-wide visibility through remote monitoring, helping detect issues before they become problems, boost productivity and reduce downtime. IoT Solution Pack is flexible and scalable. Facilities can start with a small number of target devices and grow over time by adding devices or integrating with other systems. — *Toshiba America, Inc., New York, N.Y.*

solutions.toshiba.com

An expanded line of intelligent pumps

This company has expanded its HiLobe series Roots pumps (photo), which are available in a broad spectrum of pumping speeds and applications. HiLobe Roots pumps are particularly suited for rapid evacuations (lock chambers or leak-detection systems) and for general coating applications. With their individual speed control, these vacuum pumps can be adapted to specific requirements and can handle a wide range of nominal pumping speeds up to 6,200 m^3/h. Their drive concept enables around 20% shorter pump-down times than conventional Roots pumps, says the company. The HiLobe series can provide over 50% reduction in maintenance and energy costs compared to conventional Roots pumps, due to the energy-efficient drives that meet the future IE4 energy-efficiency class. — *Pfeiffer Vacuum GmbH, Asslar, Germany*

www.pfeiffer-vacuum.com ■

Mary Page Bailey and Gerald Ondrey

Atmospheric Storage Tanks: Roof Classifications

Department Editor: Scott Jenkins

Storage tanks that are freely vented to the atmosphere are known as aboveground atmospheric storage tanks (ASTs). ASTs have a vertical cylindrical configuration and can be identified by the open vent nozzle on the tank roof. This one-page reference outlines the classifications for ASTs based on roof type, and provides information on tank construction.

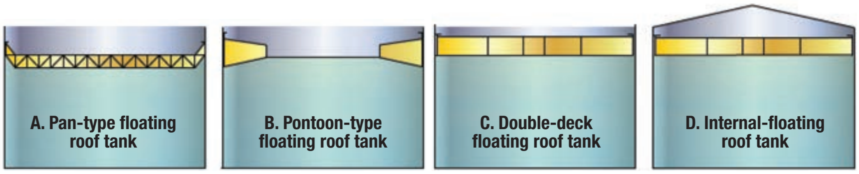

FIGURE 1. Types of floating-roof tanks include the following: A) pan; B) pontoon; C) double-deck floating roof tank; and D) internal-floating roof tank [*1*]

Tank roof types

Two basic types of vertical-tank roof designs exist — fixed or floating roof.

Fixed roof. In this design, the tank roof is welded, and the shell and the roof remain static. Fixed-roof tanks consist of a cylindrical shell with a permanently welded roof that can be flat, conical or dome-shaped. As a rule of thumb, fixed-roof tanks are used to store liquids with true vapor pressures (TVP) of less than 10 kPa (absolute) [*2*]. TVP is the absolute pressure when the vapor is in equilibrium with liquid at a constant temperature.

Floating roof (internal or external). In this design, the tank roof floats on the liquid surface and rises and falls with changes in liquid level. These tanks reduce evaporation losses and control breathing losses while filling. Floating roofs are preferred for tanks storing petroleum products with a TVP of 10.3 to 76.5 kPa absolute. For liquids with flashpoint below 37.8°C, excessive loss of volatile liquids occurs from the use of open-vented fixed-roof tanks. Hence, floating roofs are mostly used for liquids with flash points below 37.8°C [*2*]. Flashpoint is the lowest temperature, (corrected to a barometric pressure of 101.3 kPa(a)) at which application of a flame test causes the vapor of the test portion to ignite under the specified conditions of the test.

The internal floating-roof tank (IFRT) has a permanent fixed roof with a floating roof inside, while the external floating-roof tank (EFRT) consists of an open-topped cylindrical shell with a roof that floats on the liquid. There are principally three different types of external floating roofs (Table 1) along with the internal floating-roof tank (Figure 1). IFRTs are preferred in areas of heavy snowfall, where accumulation of snow or water on the floating roof may affect buoyancy. In such tanks, the vapor space is normally blanketed with an inert gas [*1*].

In an IFRT, tank vapor space located above the floating roof and below the fixed roof includes circulation vents to allow natural ventilation of the vapor space. This action reduces the accumulation of product vapors and possible formation of a combustible mixture [*2*].

TABLE 1. TYPES OF FLOATING-ROOF TANKS [*1*]

Type	Characteristics
Pan-type roof	• Single-deck roof • Full contact with liquid surface • Has a deck, hence any leak through the deck will cause it to sink • Has no buoyancy other than that provided by the deck • Rain or snow may cause deformation • Is the least expensive of the floating roofs
Pontoon-type roof	• Increased buoyancy and stability • Pontoons occupy about 20–40% of roof area
Double-deck roof	• Comprises upper and lower decks separated by bulkheads and trusses • The space between the decks is separated into liquid-tight compartments • Superior loading capacity • Recommended for tank diameters below 12 m and above 60 m

Physical criteria

ASTs may be shop-welded or field-welded and are customarily fabricated from structural quality carbon steel, such as A-36 or A-283 Gr.C. [*2*] The vertical cylindrical shape and relatively flat bottom helps to keep costs low. Typically, ASTs are considered to have an operating pressure ranging from 0 to 0.5 psig. Tanks designed to operate at pressures between 0.5 and 15 psig are termed as low-pressure storage tanks. Designs above 15 psig are treated as pressure vessels.

Tank capacity. Three different types of tank capacity are defined — nominal, gross and net capacity. For fixed-roof tanks, the nominal capacity is the geometric volume from the bottom of the tank up to the curb angle, which is a metallic angle that is welded along the periphery at the top of the cylindrical portion of the tank. In the case of floating-roof tanks, the nominal capacity is defined as the volume from the underside of the roof deck up to the maximum floating position of the roof. The gross capacity (sometimes referred to as the total capacity) is the volume from the bottom of the tank up to its maximum, safe filling height. The net capacity is the volume of the tank contents between the low-liquid level (LLL) and the high-liquid level (HLL).

Tank dimensions. In general, tank heights do not exceed one and a half times the diameter. In cases where availability of land is not a constraint, it is justifiable to go for larger diameters in preference to height. As the tank height increases, wall thickness plays a more important role. Higher tanks also put a greater load on the soil. If the pressure becomes more than the soil-allowable bearing pressure, pile-supported foundations become necessary and are expensive. This concern is particularly applicable for poor soils. In general, tanks that are higher than 15 m are not commonly used in industry. ■

Editor's note: The material in this column was adapted from the articles referenced here:

1. Mukherjee, S., Understanding Atmospheric Storage Tanks, *Chem. Eng.*, April 2006, pp. 74–84.
2. Kenkre, P.D., Designing Atmospheric Storage Tanks, *Chem. Eng.*, March 2017, pp. 77–82.
3. Benz, A., Storage Tanks, *Chem. Eng.*, December 2019, pp. 34–37.

Propionic Acid Production from Propionaldehyde

By Intratec Solutions

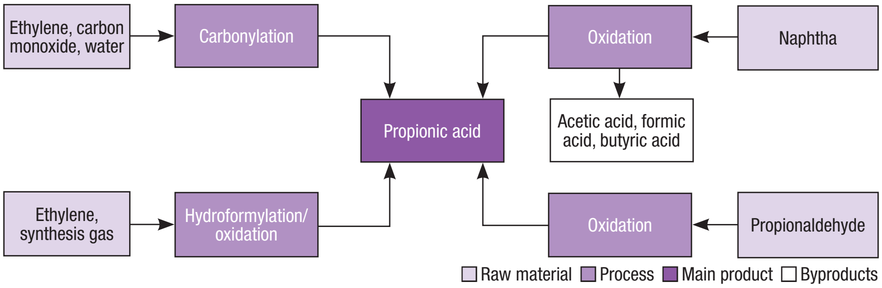

FIGURE 2. Propionic acid production pathways vary according to starting materials

Propionic acid (also known as propanoic acid) is a carboxylic acid commonly found in nature, mainly in its ester form in some essential oils. This fatty acid is also formed in a number of enzymatic and fermentation processes. Widely used in the production of cellulose esters, plastic dispersions and herbicides, propionic acid has gained importance in recent years for applications related to preservation of forage-cereal crops and animal feeds.

The uses and applications of propionic acid vary according to the product grade. The main form of propionic acid is one with 99.5 wt.% minimum purity. Most industrially produced propionic acid is used as a preservative in stored animal feed and grain. Examples of its agricultural applications include its uses as the following: an antibacterial additive (for livestock and poultry drinking water); a surface sanitizer (in storage areas for silage and grain); a poultry-litter additive; and for use with high-moisture grains in indoor storage. To a lesser extent, propionic acid is also used as a food additive and chemical intermediate for herbicides, pharmaceuticals, rubber products, plastics and plasticizers, among others.

The process

The present analysis discusses an industrial process for propionic acid production. The process comprises two major sections: (1) propion aldehyde oxidation; and (2) propionic acid separation (Figure 1).

Propionaldehyde oxidation. Initially, propionaldehyde in the liquid phase is fed to three tube-and-shell reactors operating in series, where it is oxidized to propionic acid under mild pressures in the presence of air. Crude acid taken off at the bottom of the last reactor is routed to the separation and purification steps downstream.

Propionic acid separation. The crude acid is fed to a decomposition column, where perpropionic acid (contaminant) is decomposed by heating under positive nitrogen pressure. Then, unconverted propionaldehyde is recovered in a subsequent column and recycled to the oxidation reaction. The propionic-acid-rich stream is routed to a light-ends column for the removal of light impurities and high-purity propionic acid (99.5 wt.%) is finally obtained by azeotropic distillation using ethyl acetate as an entrainer.

Production pathways

At commercial scale, propionic acid can be produced through three main routes, including oxidation of propionaldehyde, depending on which raw starting materials are used. Propionic acid can also be produced by carbonylation of ethylene with carbon monoxide and water, and as a byproduct from the direct oxidation of hydrocarbons. Different pathways for propionic acid production are presented in Figure 2.

Economic performance

The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce propionic acid was about $830 per ton of propionic acid in the fourth quarter of 2016. The analysis was based on a plant constructed in the U.S. with the capacity to produce 80,000 metric ton per year of propionic acid.

This column is based on "Propionic Acid Production from Propionaldehyde – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/propionic-acid-production-cost. ■

Edited by Scott Jenkins

Editor's note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented are prepared on the basis of publicly available and non-confidential information. The content represents the opinions of Intratec only. More information about the methodology for preparing analysis can be found, along with terms of use, at www.intratec.us/che.

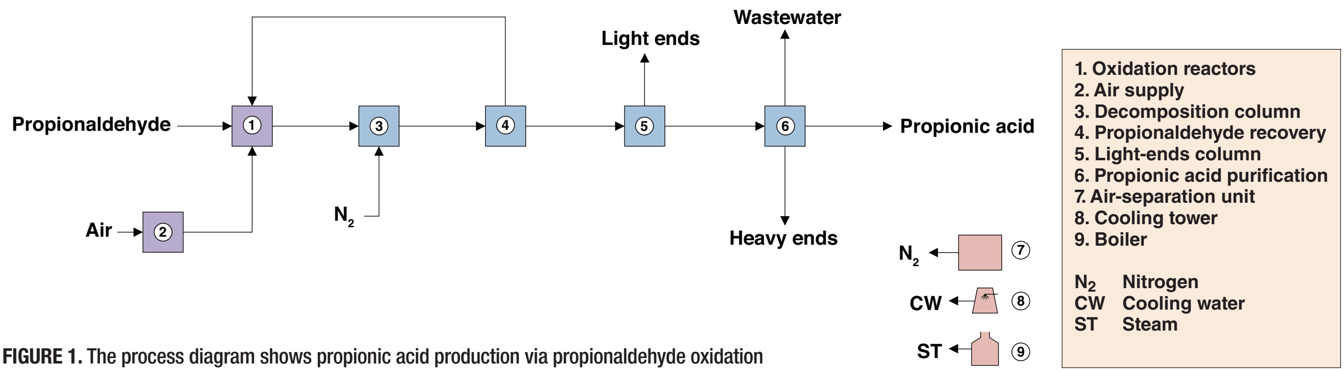

FIGURE 1. The process diagram shows propionic acid production via propionaldehyde oxidation

Software Powers the CPI

IIoT technologies have enabled software platforms that are more powerful than ever, but fundamental engineering principles are still at the heart of next-generation digital transformation

It is clear that the emergence of industrial internet of things (IIoT) technologies has greatly expanded the capabilities of industrial software tools. Although IIoT's recent proliferation in the chemical process industries (CPI) may seem to be primarily driven by advances in software and other digital tools, such as artificial intelligence (AI) and cloud computing, these elements have built upon the types of solutions — as well as fundamental engineering principles — that have been deployed for several decades.

Software's digitalization journey

"The industry has been practicing digitalization for a long time, and the recent changes have made these applications more powerful, agile, portable, intelligent and autonomous. Evolution in the CPI is gradual; it is incremental due to the intrinsic liability associated with the operation of an industrial plant," says Sergio Fernandes, chemical market leader, Yokogawa Corp. of America (Sugar Land, Tex.; www.yokogawa.com/us). Nonetheless, CPI companies have successfully deployed digital technologies at a large scale, catalyzed in part by the shift from software being run on a user's laptop to the reality that high-performance applications and tools can now be accessed from almost literally anywhere. "Not only has cloud computing enabled a reduction in capital expenditure budgets, it has also facilitated the availability of process models, whether steady-state or dynamic, regardless of the end user's location," explains Fernandes. However, he cautions against simply assuming that a digital plant model, no matter how advanced, will be fully accurate in perpetuity. "Industrial processes are like living entities — they change with time. Any mathematical representation, such as a digital twin, needs to adapt and needs to be updated by some mechanism. Otherwise, it will eventually fall into disuse. Assets require attention; they demand budgets to maintain their sustainability," he adds. Envisioning a future with increasingly autonomous operations, the critical need for safety and sustainability means that a smart balance must be struck when deploying human resources alongside digital assets. "Risky field operations, repetitive actions, mundane activities, unnecessary trips to collect data in the field and inspection in hazardous areas can be intelligently addressed by current and upcoming technologies," says Fernandes, framing cutting-edge digital technologies as critical components that will enable an architecture that fosters more innovation from humans. "That means continuous improvement of operations, the anticipation of the next disruption and the optimization of the whole value chain."

Simply developing a software model that mimics a process or asset is not enough to truly capitalize on the promise of digitalization, reiterates Rajesh Ramachandran, chief digital officer of ABB Industrial Automation (Zurich, Switzerland; www.abb.com). "What's trending now is the industrial AI twin of a digital plant. This looks at how to predict and optimize a set of outcomes for a specific process scenario, giving the opportunity to fine-tune different parameters," he explains. Ramachandran emphasizes that pure AI cannot be applied "as-is" into an industrial context — corresponding domain expertise is essential to capture the complexities of CPI operations, such as the quality specifications for end products or the varying presence of feedstock impurities. ABB has combined data-driven AI with domain expertise built deep into the digital twin, ultimately building a cognitive model through its ABB Ability Genix software platform. "Genix builds something we call a cognitive model that expands upon advanced models with domain knowl-

FIGURE 1. Along with having a view of the process in a digital twin, an analytical software platform can provide automated root-cause analysis on any process issues or deviations, including recommended actions

edge from different systems, such as maintenance, instruments and laboratories. What that means is that it helps to make more accurate predictions for optimization," adds Ramachandran. Citing industry studies that showed on average, a plant may only use around 27% of its produced data, while engineers may spend as much as 80% of their time aggregating data, he predicts that cutting-edge software platforms will help to alleviate these imbalances. "We are investing in fundamentally addressing areas of need to unlock the value in unused data and apply industrial AI at scale to get the maximum productivity and operational gains, while also simplifying the efforts toward data integration," he says.

Intelligent platforms

There is no doubt that industrial software platforms have gotten considerably more powerful in recent years, as more companies are embracing use cases for industrial AI and machine learning (ML). "In the CPI, these types of technologies are being integrated everywhere from asset monitoring to AI-powered drones than can inspect flare stacks," explains Michael Tworzydlo, product manager for analytics and machine learning at Emerson (St. Louis, Mo.; www.emerson.com). However, Tworzydlo cautions against overhyping the value of these solutions without acknowledging the importance of foundational engineering principles. "As chemical engi-

neers, the fundamentals of analytics are the best starting place, and that begins with principles-driven analytics, based on physical laws, such as how a heat exchanger works. Then, organizations can evolve to data-driven approaches that leverage AI or ML for more complex processes or plant-wide issues," he adds.

"AI offers powerful capabilities to the CPI, but some companies struggle to effectively apply it to manufacturing challenges," explains Paige Morse, chemicals industry director at Aspen Technology, Inc. (Bedford, Mass.; www.aspentech.com). dc

As a response, AspenTech has begun embedding AI into its software platforms, which makes it more accessible to a broader mix of users. The combination of first-principles engineering with AI and domain expertise, Morse notes, can help users to better find solutions for the complex problems that must be navigated in the CPI. AspenTech's Hybrid Models approach can not only aid in process optimization, but can also empower engineers to create custom soft sensors, design new equipment and integrate asset-wide processes. "Engineers can now build enriched models faster using ML to leverage simulation or plant data, adding domain expertise, engineering principles and design constraints, without requiring deep process or AI expertise," says Morse. As many CPI companies are facing legitimate skills gaps, technologies that empower workers to tackle tasks that were previously reserved for experts or specialists are especially vital.

In addition to overcoming workforce gaps, sustainability initiatives are another area where CPI companies are increasingly focusing their efforts. "Cost savings have driven many digitalization efforts, but companies are increasingly focused on waste and emissions from production units, as well as efficiency and reliability enhancements," says Morse. "Process simulations aid the development of new products to address the technical challenges of the circular economy, such as molecular recycling and new plastic design, and this activity moves even faster when aided by AI," she adds.

FIGURE 2. Building upon existing training technologies by using extended reality and the cloud, along with digital-twin capabilities, promises significant safety benefits and cost savings

Such predictive capabilities are increasingly valuable in meeting specific sustainability goals, such as reducing air pollution with predictive emissions-monitoring systems (PEMS), a functionality of Emerson's Plantweb Optics Analytics platform (Figure 1), which deploys ML and AI with digital twins and distributed control systems. "As part of Plantweb Optics Analytics, we can deploy PEMS that monitor and estimate emissions using models and ML to dynamically opti-

mize production. With PEMS, we can build models based on process variables that we are already capturing and use those to estimate, and ultimately reduce, emissions," says Tworzydlo.

Extending reality

In addition to AI and ML, augmented reality (AR) and virtual reality (VR) software platforms are also on the rise in industrial plants — and owing to the increased need for remote work during the pandemic, these sorts of technologies are no longer seen as "luxury" items and are more useful than ever. "Due to the pandemic, fewer people are in plants, and plants are embracing new technologies. AR allows digital information to be overlaid onto the real world, and this helps better equip workers to complete tasks accurately and with fewer interruptions," says Emerson's Tworzydlo. As for the future of AI, ML and AR in industrial software, the use cases will surely continue to expand. "There is still a lot of untapped potential. Eventually, we will start moving into autonomous operations for certain processes, where those processes increasingly become self-diagnosing and self-healing," Tworzydlo predicts.

Aveva Group plc (Cambridge, U.K.; www.aveva.com) has bundled AR and VR concepts into extended reality (XR) platforms, with one particularly pertinent application being personnel training (Figure 2). "XR immersive training systems allow companies to capture and retain operational knowledge during the replacement of retiring experienced operators, which is critical for plant safety and performance. This behavioral training can be applied not only for front-line operators, but also for engineers, technicians and emergency personnel," explains Ravi Gopinath, chief cloud officer and chief product officer at Aveva.

In one instance, an operator-training scheme developed by Aveva and Shell (The Hague, the Netherlands; www.shell.com) focused on behavioral training to increase safety competencies. "With this behavioral approach, the operator can be trained and assessed on how he or she will behave when faced with unexpected or infrequent situations in the plant," says Gopinath. In another project, Aveva and Adnoc (Abu Dhabi; www.adnoc.ae) created a real-time data-visualization center that brings together over 120 dashboards and 200,000 data points on a massive interactive screen.

Training is just one part of XR's potential. AR tablet-based applications are already being used to support field workers. Connecting the VR model in the tablet to real-time information and guided procedures with AR enables better work execution, preventing costly failures and reducing downtime. Looking toward the future, Aveva believes that XR software will significantly improve facility design and capital project engineering by enabling the automatic import of conventional 3D plant models, which are used during the design phase, into an immersive environment. "This conversion into VR will allow the ergonomic design to be reviewed and improved before any equipment is even purchased. The virtual plant can already exist entirely in the cloud, allowing collaboration between engineers at different offices or even on different continents.

With this approach, the project can access diverse expertise without any travel and the design review is executed faster, with less cost and risk," emphasizes Gopinath.

Looking outside the box

As software platforms' data-capture and analysis capabilities have progressed, powerful analytics tools have become self-service, scalable decision-making tools for chemical engineers, into which they can build their own functionalities to meet specific process needs. With such democratized tools, engineers can leverage data from disparate sources — for instance, laboratory information like batch quality can be linked to process data alongside maintenance data, says Edwin van Dijk, vice president of marketing at TrendMiner N.V. (Hasselt, Belgium; www.trendminer.com). "The goal of democratizing analytics is to enable everybody in operations, from control room to boardroom, to use actionable insights for making data-driven decisions. This goes beyond traditional dashboarding tools by allowing the users to create their own dashboards based on fingerprints, monitors and context views," adds Van Dijk. Through pattern recognition, engineers can investigate operational performance and use good operational behavior for process monitoring. Furthermore, they can create their own "soft" sensors to monitor what physical sensors cannot measure, such as product-quality specifications.

A data-analytics success story reported by TrendMiner involved a chemical plant that was experiencing "sticky" valves, which were creating a delay between the valve's output changing and the actual process responding. The plant wanted to accurately identify when a valve was beginning to stick, so they needed to monitor for any deviations from the valve's expected behavior and then find the parameters that distinguished between periods of "good" and "bad" valve behavior. These parameters were translated into alerts for out-of-phase behavior that would not only notify personnel about the situation, but also suggest possible corrective actions (Figure 3). "By using the self-service analytics solution, the process

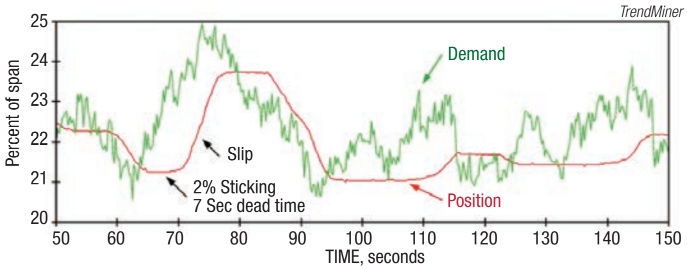

FIGURE 3. Advanced analytics techniques can help engineers with an in-application recommender engine, suggesting potential root causes for process issues such as valve stickiness

experts were able to use high-speed trend analysis to search and validate production issues, using embedded AI and ML capabilities," explains van Dijk.

Even with the vast selection of software tools and mobile apps available, some users still require highly customized solutions to meet their business needs. This is where in-house programming can come in handy. JourneyApps (Denver, Colo.; www.journeyapps.com) offers a high-productivity app-development platform, with which users can write their own code, enabling more complex apps than no-code app-building tools, which are aimed at non-programmers and are limited by their simplicity. "This means that advanced business logic, engineering calculations and highly customized integrations can be implemented in a matter of days without much of the traditional overhead associated with software development," explains Conrad Hofmeyr, CEO of JourneyApps. He points out that most chemical engineers have some basic coding or scripting experience through tools like Microsoft Excel Macros or Matlab, so they can quickly pick up the necessary programming skills to use JourneyApps to build sophisticated apps that automate and streamline key business functions.

For instance, Hofmeyr cites an example where a CPI company built a dedicated app for standard operating procedures (SOPs) that enabled them to shift from manual spreadsheet-based SOPs to a centrally controlled app with full audit trails. "The customizability that JourneyApps provides meant that a single, global app could be customized to local requirements and system integrations," he adds. In another example, an oilfield-chemicals manufacturer developed its own app to run key calculations used daily in its field-reporting processes and generate reporting documents, all while users are offline at disconnected sites.

Looking toward end uses

Advanced software and modeling tools are also enabling the creation of safer, more effective end products in many industry sectors, from automotive parts to pharmaceuticals. One example is BASF SE's (Ludwigshafen, Germany) Ultrasim computer-aided engineering (CAE) tool for simulating materials behavior (Figure 4), which was recently updated to model an extended range of thermoplastic elastomer materials over the entire process chain, from initial processing to end-use products. "Shrinking development cycles and aggressive timelines put an increased amount of stress on engineers to get product performance right the first time. Having predictive accuracy offers tremendous advantages," says Marios Lambi, team leader for BASF Simulation Engineering CAE, North America. Ultrasim enables the simulation of both initial load and cyclic loads on a component, which proves to be particularly essential for automotive parts made of elastomeric materials. "From creep loads to crash simulations and thermal loads and vibrational behavior, coupled with processing simula-

FIGURE 4. Ultrasim involves models that incorporate anisotropic (directionally dependent) fiber orientation in a mechanical simulation of a technical part, along with materials models that look at the dependency of the material behavior to the speed of deformation

tions, which describe process-induced material properties, and numerical optimization tools, which allow fast geometrical variations, Ultrasim builds the basis for designing better parts," emphasizes Andreas Wüst, team leader for BASF Dynamic Structural Analysis, Europe.

The foundation for ensuring accurate materials simulation is the underlying data. "The material-characterization process generates the necessary data that are essential in the accuracy in predicting real part behavior. The theoretical material models developed for this purpose are using the information from testing to calibrate and therefore ensure the behavior represents real manufacturing conditions and not an arbitrary case that is far from reality," Lambi points out. "There are complicated assembly examples, such as automotive seating, which are subjected to crash testing that utilize Ultrasim's predictive accuracy to build parts that pass validation testing. This dramatically reduces the development cycle and minimizes, if not eliminates, design changes," he adds. Ultrasim also provides capabilities for the growing market share of 3D-printed parts, which can now be investigated using the tool, further accelerating the cycle time from design to prototype to end product.

For the high-precision processes in research and development and quality-analysis laboratories for biopharmaceutical ingredients and other high-value products, software tools can serve several purposes, including the facilitation of an organization's business continuity plan (BCP). "When looking at the laboratory, efficient software can mitigate or reduce the number of risks, streamline testing of events, have automated procedures to restore the system once an event is over and even keep the system running during an event, all simplifying the BCP," says Barbara van Cann, product marketing manager for chromatography software in the Enterprise Chromeleon Data System organization at Thermo Fisher Scientific (Waltham, Mass.; www.thermofisher.com). Moreover, laboratories can further streamline their BCP by selecting integrated software that encompasses the chromatography data system (CDS), the laboratory information-management system (LIMS) and the laboratory execution system (LES). "Both LIMS and CDS software should provide tools to monitor instrument qualification, calibration and maintenance, even down to individual component parts," explains Van Cann. The CDS software should also help users to deal with analytics irregularities, as well as have built-in network failure protection to ensure continued operations, without manual interaction, in the event of network outages. To avoid outages due to cybersecurity attacks, Van Cann advises that laboratories run CDS and other software on a domain separated from main office systems to avoid potential cyber-threats originating from emails. Finally, as with any automated software platform, the human element must be considered. "Human error can be reduced by controlling what users can and cannot do, and can and cannot access. In addition, there should be tools to automate as many actions as possible. Less user interaction equals fewer errors," she adds. ■

Mary Page Bailey

Design of Bulk-Solids Moving-Bed Heat Exchangers

Presented here are equations governing heat transfer in a moving-bed heat exchanger, along with a numerical method for solving them

Greg Mehos
Independent consultant

IN BRIEF

HEAT TRANSFER BETWEEN PLATES

SOLVING THE EQUATIONS

Moving-bed heat exchangers (MBHE) represent an efficient method for heating or cooling bulk-solid materials compared to other technologies, such as screws and fluidized beds. This article describes the equations governing heat transfer in an MBHE, and provides information on a numerical method to solve the equations.

In a bulk-solids moving-bed heat exchanger, a flowing bed of solid particles indirectly exchanges energy with a secondary heating or cooling medium across a separating wall. MBHEs typically consist of hollow parallel plates. The bulk material flows, driven by gravity, between adjacent plates, while the heat-transfer fluid flows inside the plates. Beneath the heat-exchanger plate bank is a mass-flow hopper, followed by a feeder that modulates the solids flowrate and keeps the channels between the plates filled with bulk material. In a mass-flow hopper, all the solids are in motion during discharge. Refer to Ref. 1 for procedures for designing mass-flow hoppers.

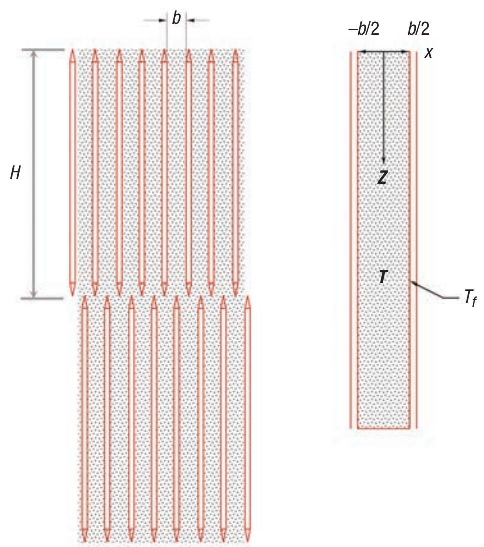

FIGURE 1. Moving-bed heat exchangers have downward-flowing solid material with heat-transfer fluid inside plates

Heat transfer between plates

Consider the streams of bulk solids and heating or cooling fluid moving countercurrently inside the plates of a heat exchanger, as shown in Figure 1. The plates are separated by a distance b, and each plate has a height equal to H. The heat exchanger may be composed of multiple banks of heat-transfer plates that are offset from each other.

If an assumption is made to neglect radiation, then heat transfer from the walls of the heat-exchange plates to the moving bed of solids can be described by Equation (1).

$$\rho_b u C_{Ps} \frac{\partial T}{\partial z} = k_{eff} \frac{\partial^2 T}{\partial x^2} \tag{1}$$

where ρ_b is the bulk density of the solids material, u is the solids velocity through the channels, C_{Ps} is the heat capacity of the solid particles, T is the temperature of the solid materials, z is the axial position, k_{eff} is the effective thermal conductivity, and x is the transverse distance. The solids velocity can be calculated from Equation (2).

$$u = \frac{\dot{m}_s}{\rho_b L b} \tag{2}$$

Where $\dot{m}_s$ is the solids flowrate and L is the length of a heat exchanger plate.

The boundary conditions for this situation are as follows in Equations (3a) and (3b).

$$-k_{eff} \frac{\partial T(-\frac{b}{2}, z)}{\partial x} = h[T(-\tfrac{b}{2}, z) - T_f(z)] \tag{3a}$$

$$-k_{eff} \frac{\partial T(\frac{b}{2}, z)}{\partial x} = h[T(\tfrac{b}{2}, z) - T_f(z)] \tag{3b}$$

where h is the heat-transfer coefficient, and T_f

is the bulk temperature of the heat-transfer fluid. The fluid temperature will change as heat is transferred between the fluid and moving bed of solids, according to Equation (4).

$$T_f(z) = T_{fout} + \frac{\dot{m}_s C_{Ps}}{\dot{m}_f C_{Pf}} (\bar{T}(z) - \bar{T}_{sin}) \quad (4)$$

where $\dot{m}_s$ is the mass flowrate of the fluid, C_{Pf} is the heat capacity of the heat-transfer fluid, $\bar{T}$ is the mean solids temperature, $\bar{T}_{sin}$ is the mean solids temperature at the channel inlet, and T_{fout} is the outlet temperature of the fluid. The ratio $\dot{m}_s C_{Ps} / \dot{m}_f C_{Pf}$ is equal to the capacity ratio C.

The temperature of the bulk solids exiting the heat-transfer geometries will not be uniform. Instead, it will have a parabolic profile. However, by incorporating multiple banks of staggered heat-transfer elements arranged vertically, a more uniform temperature profile for the solids can be obtained. If the heat exchanger portion of the equipment is composed of multiple banks of vertical, parallel plates that are staggered as shown in Figure 1, particles that lie closest to a plate surface in one upper bank will fall at the center of the channels in the bank of heat-exchanger plates just below.

At the entrance to a channel, Equation (5) is true.

$$T(x,0) = T_0(x,0) \quad (5)$$

In this equation, T_0 is the initial temperature of the solids.

Solving the equations

Analytical solutions exist for the partial differential equation in Equation (1) if the heat-transfer-fluid temperature is constant and a uniform temperature profile exists for the solids at the inlet to the channel [2]. However, this is not typically the case for a moving-bed heat exchanger with staggered banks of plates and a heat-transfer fluid within the plates. In these cases, numerical methods must be used to solve the equation.

While software packages are available for solving partial differential equations, the energy balance equation can easily be solved using Microsoft Excel and VBA (Visual Basic for Applications). Equation (1) can be discretized as follows (Equations 6–20):

$$a_i T_{i-1}^{n+1} + b_i T_i^{n+1} + c_i T_{i+1}^{n+1} = d_i^n \quad (6)$$

With

$$a_i = -\lambda,\ i = 1, 2, \ldots, I-1 \quad (7)$$

$$b_i = 1 + 2\lambda,\ i = 1, 2, \ldots, I-1 \quad (8)$$

$$c_i = -\lambda,\ i = 1, 2, \ldots, I-1 \quad (9)$$

$$d_i^n = T_i^n,\ i = 1, 2, \ldots, I-1 \quad (10)$$

$$a_1 = 0 \quad (11)$$

$$b_1 = 1 + \frac{k_{eff}}{h\Delta x} \quad (12)$$

$$c_1 = -\frac{k_{eff}}{h\Delta x} \quad (13)$$

$$d_1^n = T_f^n \quad (14)$$

$$a_I = -\frac{k_{eff}}{h\Delta x} \quad (15)$$

$$b_I = 1 + \frac{k_{eff}}{h\Delta x} \quad (16)$$

$$c_I = 0 \quad (17)$$

$$d_I^n = T_f^n \quad (18)$$

Where

$$\lambda = \frac{k_{eff}\,\Delta z}{\rho_b C_{Ps}\, u (\Delta x)^2} \quad (19)$$

and

$$T_f^n = T_{fout} + \frac{\dot{m}_s C_{Ps}}{\dot{m}_f C_{Pf}} (\bar{T}^n - \bar{T}_{sin}) \quad (20)$$

The subscript i represents the discretized distance in the x direction. The subscript n represents the distance in the z direction. In matrix form, this is represented by Equation (21).

$$\begin{bmatrix} b_1 & c_1 & & & \\ a_2 & b_2 & c_2 & & \\ & a_3 & b_3 & \ddots & \\ & & \ddots & \ddots & c_{I-1} \\ & & & a_n & b_I \end{bmatrix}^n \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ \vdots \\ T_I \end{bmatrix}^{n+1} = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ \vdots \\ d_I \end{bmatrix}^n \quad (21)$$

This system of linear algebraic equations can be solved using the Thomas algorithm for tridiagonal matrices. The VBA programming code for the Thomas algorithm is shown in Figure 2.

```
For K = 1 To N

    M = A(K) / B(K - 1)

    B(K) = B(K) - M * C(K - 1)

    D(K) = D(K) - M * D(K - 1)

Next K

T(Nx) = D(N) / B(Nx)

For K = N - 1 To 0 Step -1

    T(K) = (D(K) - C(K) * T(K + 1)) / B(K)

Next K
```

FIGURE 2. Visual Basic for Applications (VBA) can be used to solve a tridiagonal matrix system of equations by the Thomas algorithm

To illustrate how the equations shown in this article can be used to design an MBHE, the following example is provided. The goal was to design a heat exchanger that would heat the bulk material from 20°C to 100°C. The analysis was completed with the following inputs:

$\dot{m}_s$ = 5 kg/s
C = 0.0625
C_{Ps} = 1,300 J/kg-s
ρ_b = 1,000 kg/m^3
k_{eff} = 0.57 J/m-°C
h = 150 W/m^2-°C
T_0 = 20°C

Results

T_{fout} = 141°C
b = 0.05 m
N = number of plates = 21
L = 1 m
H = 1.5 m (two banks)

As the bulk material travels between the heat exchanger plates, its temperature increases. The increase in temperature is more significant closest to the walls of the plates (Figure 3). If staggered banks of plates are used, the lower-temperature particles leaving the channels between a row of plates will be closest to the walls of the next row of plates (Figure 4). In this

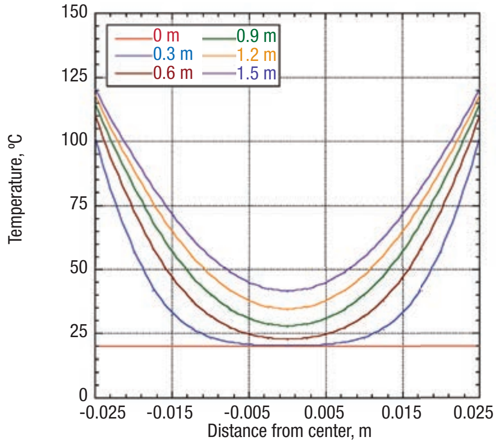

FIGURE 3. As bulk material flows between exchanger plates, the temperature increase is higher closest to the walls

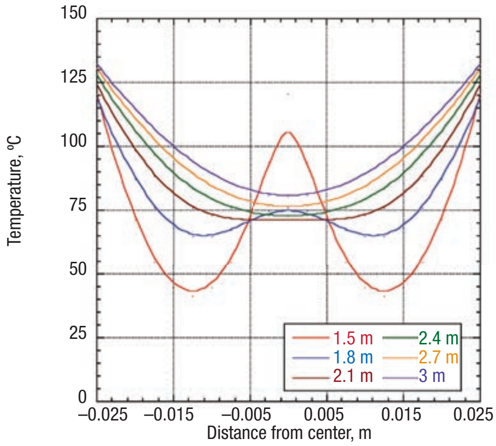

FIGURE 4. With staggered banks of plates, particles between plates will be closest to the walls of the next row of plates

example, the mean temperature of the bulk-solid material increases as it moves downward through the heat exchanger plates. The temperature of the heat-transfer fluid decreases as it flows upward (Figure 5). ■

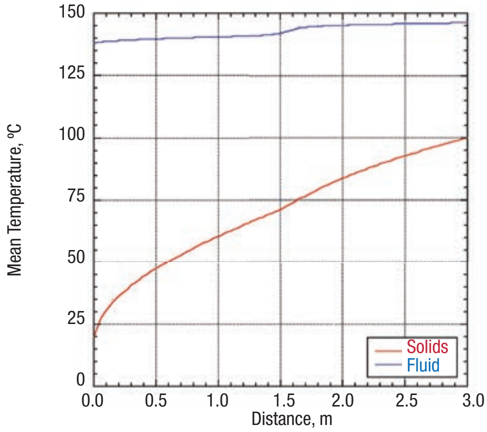

FIGURE 5. The mean temperature of the bulk material increases as the solids move downward

Edited by Scott Jenkins

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Thermodynamics of Gas Piping Systems

Understanding the implications of adiabatic and isothermal flow assumptions is necessary to have confidence in when to use such assumptions

Walt Prentice
Applied Flow Technology

IN BRIEF

Every engineer uses assumptions because every analysis has an overabundance of variables to consider. Often, there are just too many to analyze and simplifications are made to eliminate variables or create more relationships between them. The decision of what assumptions to make rests on the engineer's shoulders. Even beyond making a problem solvable, engineers build assumptions into their analyses to make the math easier and faster. Although a problem may be technically solvable, there is value in simplifying the problem further. After all, exact answers do not exist in engineering.

When analyzing something as complex as gas flow through pipes, the math becomes daunting to say the least. Hydraulic modeling of liquid and gas systems are worlds apart, simply because gases have variable density, while liquids do not. (This may not sound like a huge difference, but open a compressible flow textbook, and you will quickly change your mind.)

With all the intricate considerations of compressible flow, heat transfer complicates the situation exponentially. Yet, without analyzing heat transfer, the system model may deviate far from reality. Flow behavior, among other things, relies heavily on temperature. This leaves engineers with a dilemma and often pushes them to simplify their operating conditions with assumptions to make the math easier. Two common assumptions in gas-handling processes are (1) adiabatic flow and (2) isothermal flow. The derivations, implications and outcomes of each assumption need to be understood before an engineer puts confidence in them.

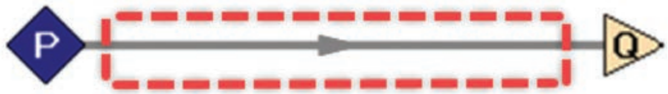

FIGURE 1. Shown here is a hypothetical methane-transfer system. Methane enters at pressure (*P*) 300 psia (20.5 bars) and 100°F (38°C), with a flowrate (*Q*) of 5,000 scfm (8,500 scmh). The surrounding air is 60°F (16°C) with low wind at 5 ft/s (1.5 m/s). The system boundaries are represented by the dotted red line. The system is the enclosed pipe [*1*]

System and boundaries

In any thermodynamic study, defining the system and its boundaries is fundamental. Heat transfer inherently implies energy is transmitted from one point in space to another, thus, crossing some boundary. Similar to defining a reference point in physics, defining the system and boundaries is up to the engineer, as there is technically no "correct" definition. (That is not to say some choices are not better than others.) The boundaries encompass the system. Everything outside the boundaries is considered the surroundings. Once the system and boundaries are defined, analysis is to be done keeping those definitions constant.

In this case, the system is defined as a piping network, where the boundaries contain the pipes and insulation but exclude any upstream and downstream energy-adding components (such as compressors or heat exchangers). In this way, only heat transfer with the surroundings is considered, and work is excluded from the energy balance. A simplified example of a single pipe is shown in Figure 1. The boundaries are represented by the dotted red line, and the system is the enclosed pipe.

To help solidify the discussed concepts, a hypothetical methane-transport system serves as a tangible example. The system conditions are described in Figure 1. Other properties, such as pipe length, diameter, and insulation thickness, are modified throughout the discussion to analyze the applicability of adiabatic and isothermal flow. However, the inlet conditions, ambient temperature, fluid-mass flowrate and pipe diameter remain constant.

This discussion is focused on steady-state flow systems. Any energy that enters the system must leave, but it may do so as a different form. The full energy balance includes five main components: heat, work, energy from

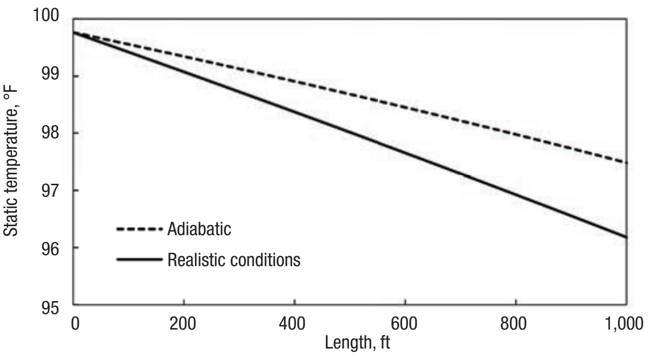

FIGURE 2. Comparing the adiabatic assumption (dotted line) with realistic heat transfer (solid line) of a 1,000 ft (300 m) pipe with a 3-in. (7.5 cm) diameter 1-in. (2.5 cm) thick insulation

fluid flow in, energy from fluid flow out, and energy accumulation. Right off the bat, both work and energy accumulation are eliminated. Subsequent analyses require looking at the energy balance and determining what does and does not apply. Setting up the problem before anything else is essential.

Even a seemingly simple system like this has complex behavior. Unlike incompressible flow, compressible flow cannot assume a linear pressure profile. Proper analysis requires the "system" to really be a series of infinitely short segments along the length of the pipes. In this way, a typical property difference (represented by a Greek "delta") found in the incompressible Bernoulli equation becomes a true differential.

Analytical solutions prove difficult to find, so modeling usually requires numerical methods to decide the size of these discrete sections. This article's discussion revolves around the whole system to display heat transfer concepts, but through modeling software, this system was broken into many pieces to obtain smooth property profiles. It is no wonder engineers pursue ways to simplify the math.

The two most common simplifying assumptions for flow in gas piping systems are to assume adiabatic or isothermal flow. As mentioned, there is no getting out of heat transfer analysis with compressible flow. Gases follow an equation of state, which means the temperature helps determine the volume and pressure of the system. They are coupled together such that heat transfer cannot be ignored.

Adiabatic flow

The term "adiabatic" means no heat is transferred between the system and its surroundings. In piping systems, adiabatic flow means no heat energy crosses that boundary between the system and surroundings. This approximation is applicable in systems with very slow heat transfer with the surroundings. For instance, systems with thick insulation around the pipes and relatively short pipe lengths are good candidates for this assumption.

Adiabatic systems enable the energy balance to completely ignore heat, so the balance boils down to energy internal to the pipes. The gas flowing into and out of our system boundary contains all the energy. The internal gas flow includes kinetic energy and enthalpy. Potential energy is neglected because the system inlet and outlet elevations are equal.

The combination of kinetic energy and enthalpy must be equal for flow entering and exiting the system. If one of the terms decreases at the exit, then the other must increase to maintain the balance. Kinetic energy tends to increase down the pipe, and enthalpy decreases. Velocity increases down the pipe as pressure decreases. Kinetic energy is a function of velocity, so that is why kinetic energy increases.

Enthalpy then decreases to balance the system. This usually results in a subsequent temperature decrease. This phenomenon is referred to as adiabatic cooling. Enthalpy and temperature have a direct relationship in most processes. (Helium is a common fluid that experiences the opposite effect, adiabatic heating. Depending on the governing process, it sees an increase in temperature with a decrease in enthalpy.) This is all to say that while the system does not see heat transfer, the fluid still sees a change in temperature. The focus of the following example is not on adiabatic cooling; however, it is important to understand the system's thermodynamic tendencies.

Assuming adiabatic flow can be sufficient for some systems, and it makes mathematical modeling much easier. By ignoring the single heat term in the energy balance, the amount of required data drops significantly. For example, the ambient conditions and obscure properties (such as heat-transfer coefficients and thermal conductivities) need not be known.

Figure 2 shows the temperature profiles of the initial methane-transfer system, both when under the adiabatic flow assumption and in realistic conditions. A real system can be modeled adiabatically when the pipe is relatively short, and the heat transfer is slow. Real conditions were modeled with 1 in. (2.5 cm) of fiberglass insulation around a 3 in. (7.5 cm) diameter steel pipe; heat transfer was modeled with correlations from literature.

Notice how the fluid experiences small, but noticeable, adiabatic cooling. Because the pipe is relatively short, and there is little pressure difference across the pipe, the velocity does not increase much, so the enthalpy change is slight. The important takeaway from this figure is to visualize how the adiabatic case matches with real conditions in a

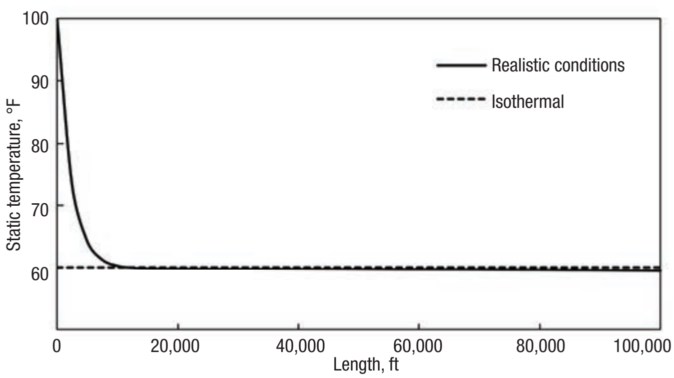

FIGURE 3. Comparing the isothermal assumption (dotted line) with realistic heat transfer (solid line) of a 100,000 ft (32,000 m) pipe with a 6 in. (15 cm) diameter and no insulation

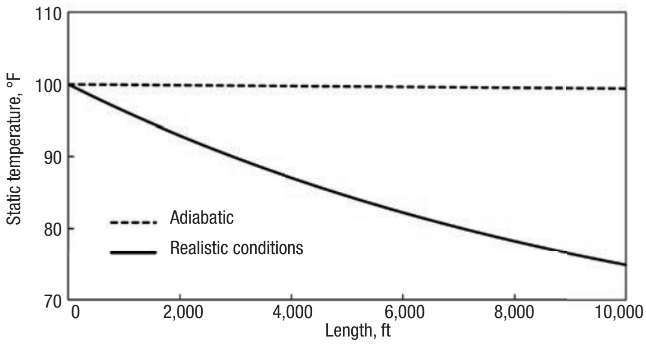

FIGURE 4. Comparing the adiabatic assumption (dotted line) with realistic heat transfer (solid line) of a 10,000 ft (3,000 m) pipe with a 6-in. (15 cm) diameter and 0.5-in. (1 cm) thick insulation

short, insulated pipe. The results are within 1.5°F (1°C) of each other.

Isothermal flow

The other common assumption in gas processes is isothermal flow. The prefix "iso" means "equal", so isothermal flow means the temperature remains constant. Because gases tend to change temperature while flowing, heat transfer occurs between the system and its surroundings to keep the temperature from changing. So, this does not immediately simplify the energy balance as far as the adiabatic model; however, eliminating even one variable in compressible flow makes the problem much simpler. In this case, isothermal flow simplifies the equation of state for analysis at different points in the system. Heat transfer and flow analysis now revolve around knowing the temperature stays constant.

The isothermal assumption is applicable in systems where heat transfer is relatively rapid. For example, very long systems with little insulation experience fast heat transfer. When there is a temperature gradient between the system and outside surroundings, heat moves between the two such that the system fluid will approach the outside temperature. The faster the fluid temperature changes to match the surroundings, the longer the temperature remains constant after the fact.

A pattern of either exponential decay (outside temperature is lower) or logarithmic growth (outside temperature is higher) exists for the system fluid's temperature. In either case, the beginning slope is always steeper than the end. The steeper the slope up front (faster heat transfer), the longer the fluid temperature profile is nearly flat. Therefore, engineers can approximate long pipes with rapid heat transfer as isothermal.

Isothermal flow can be applied whether heat is entering or leaving the system; the only criterion is that heat transfer is fast. No matter the direction of heat flow, velocity of the fluid increases with the dropping pressure, as in the adiabatic case. The major difference with isothermal flow, however, is that because temperature is constant, the corresponding volumetric flowrates and velocities are easier to

predict if pressures are known. Only pressure and volume are variable in the equation of state for the gas, as opposed to adiabatic flow, which sees variable temperature as well.

Figure 3 presents the temperature profile of the methane-transfer system assuming isothermal flow at the ambient temperature of 60°F (16°C). The pipe includes no insulation and has been adjusted to a length of nearly 20 miles (32 km) and diameter of 6 in. (15 cm). Superimposed on this graph is the corresponding profile of the realistic system model, which uses correlations from literature to determine the real heat-transfer effects of the surroundings. Notice how the temperatures are the same for the latter 90% of the pipe.

While the temperatures are quite different at the beginning, the system quickly adjusts, so the flow behavior through the system is predictable. Also notice how real conditions cause the temperature to go slightly below ambient conditions. The flow naturally wants to drop temperature and relies on the surroundings to keep it constant. When the system and surrounding temperatures are so close, there is little heat transfer between them, and the enthalpy change scarcely dominates the heat rate in. However, for practical purposes, the temperature remains constant.

Changes to the real system

When comparing the above assumptions to realistic conditions, those real scenarios were tailored for the purpose of getting answers near their ideal counterparts. The pipes were made intentionally short or long, with little or much insulation to show when the assumptions can be properly applied. In the actual field, however, such tailoring is not possible. And it is unlikely to have a system that meets all the qualifications for the assumptions to be great approximations. Again, the engineer determines what is good enough.

If the system is, instead, a length of 2 miles (3 km) for analysis of both the adiabatic and isothermal cases, the simplifications come under scrutiny. The adiabatic case no longer has a short pipeline to help match reality. And the isothermal case no longer has such a long pipeline. The system is fixed to this new length, fixed to a 6 in. (15 cm) diameter, and fixed to insulation of 0.5 in. (1 cm). The real system, if already in existence, should guide the modeling and proposed simplifying assumptions. The assumptions should not come before the real system is understood. Given this system, is the adiabatic or isothermal assumption more appropriate? At first glance, an engineer could argue for either.

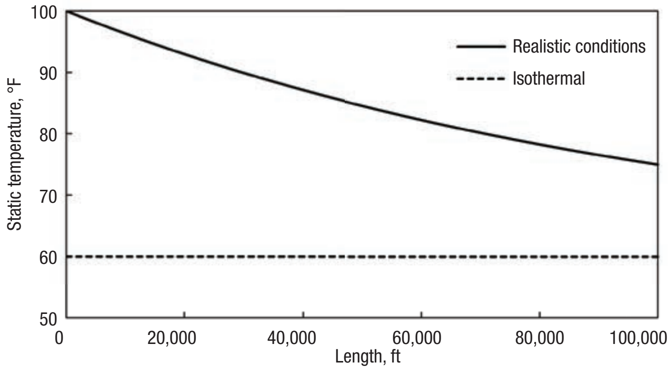

FIGURE 5. Comparing the isothermal assumption (dotted line) with realistic heat transfer (solid line) of a 10,000 ft (3,000 m) pipe with a 6-in. (15 cm) diameter and 0.5-in. (1 cm) thick insulation

The pipe is longer and has less insulation than the previous adiabatic example. Heat transfer in the real conditions will now occur more rapidly. However, an engineer still may be tempted to assume adiabatic flow because the pipe is insulated, and there is not a relatively large temperature gradient between the system and surroundings. Also, depending on other systems in question, the pipeline may be short in comparison.

However, results show a large difference between the outlet temperatures. Figure 4 compares the temperature profiles of the new adiabatic and realistic models. (Notice, again, the small adiabatic cooling effect. The pressure is still not low enough to cause much difference in kinetic energy and enthalpy between the inlet and outlet.) Depending on the downstream process, this may or may not have a large impact of process reliability. Perhaps the methane enters a heat exchanger or combustion chamber, or perhaps it is branched off to deliver to residential neighborhoods. The performance and flow distribution will be affected, but sound engineering judgment is required to decide if the difference is important.

In the adiabatic case, the properties at the system outlet see the largest difference. As the system extends, the real heat transfer occurring has more influence, and the outlet conditions diverge further from adiabatic expectations. However, the system outlet is not the only area of concern in compressible flow. It tends to be the most obvious area to look because that is what directly leads to downstream processes, but the entire temperature profile needs to be analyzed.

For instance, the largest deviation isothermal flow has from real flow occurs at the inlet of the system. The system is now much shorter than the original example. It also contains some insulation, which slows the heat transfer, so the temperature profile is not as steep at the beginning. Figure 5 shows the different temperature profiles of the new real system and the isothermal case. Compare this to the original example in Figure 3. The real system now does not reach the surrounding temperature, but it could be considered close, depending on the engineer's perspective. There is absolute deviation of 15°F (8°C), which is closer than the deviation of 25°F (14°C) from the adiabatic case.

Incorrect analysis is unlikely if the engineer is skeptical about that final difference. But if the engineer assumes the difference is no big deal, he or she needs to understand the upstream profile will differ even more so. While the system fluid still approaches the surrounding temperature, it does so much slower. Results at the outlet may falsely lead an engineer to believe an isothermal assumption is appropriate — the outlet properties can match somewhat well. And this may even be justified by the engineer claiming the pipe is long at 2 miles (3 km) and lightly insulated. However, the temperatures, flowrates and pressures are quite different along most of the pipe. This cannot be ignored.

Value of modeling software

These are mild examples of when the real case deviates from the ideal assumptions. The behavior will change depending on many factors, such as fluid, system scale, and process conditions. And the effects are more exaggerated when extreme conditions exist. Justifying assumptions as large as those discussed here can be the most difficult part of an engineer's job. Knowing the amount of error that is reasonable for a model is no easy task. It is rarely obvious what assumptions are appropriate. That is the major problem when using qualifying terms like "long" and "rapid".

The fact is a model can only be truly validated when comparing to field data. When measured data come back significantly different from the simplified model, explanation is required, but often dreaded, by the engineer. So, why do engineers have to make such simplifications in the first place? It is to untangle the math and get answers promptly, but we live in a day and age when computers do the heavy lifting.

Software allows an engineer to work through all the math (typically in a timelier manner) to obtain more accurate results. If the real conditions are different from what the ideal cases call for, then results will also differ. It depends on the engineering application whether that difference is a concern or not. For example, a controlled steam flow temperature to ensure condensation does not happen prematurely may be more important than controlling the temperature of air through pneumatic tools. However, with the complex coupling of many variables in compressible flow, being inaccurate in one variable means inaccuracy of many more. It is not so simple as choosing one property that can have large error. All properties need to come into consideration.

No system is perfectly insulated, and no pipeline is truly isothermal. When simplifications are made, error will result. The goal of the engineer should be to match mathematical models as close to reality as is reasonable and in as timely a manner as possible. The best way to accomplish this is to use modeling software that does not rely on such simplifications as incompressible solution methods or adiabatic or isothermal flow. Those may be useful for first-pass hand calculations but should not be relied upon for in-depth analysis. Compressible flow has many more complications than discussed here, such as sonic choking, so considering those affects only makes analysis harder. Do not sacrifice model quality for calculation ease. Better tools exist to help. ■

Edited by Gerald Ondrey

Reference

1. This model, and all output, was created using AFT Arrow software.

Author

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Airsets for On/Off Valve Applications

Airset regulators are seemingly simple devices, but care must be taken to ensure the right devices are specified, particularly in safety instrumented systems

Jeff Welch
Emerson Automation Solutions

IN BRIEF

HOW AIRSET REGULATORS WORK

AIRSET APPLICATIONS

AIRSET REGULATORS IN SIS

SELECTION CONSIDERATIONS

Chemical plants and other heavy industrial facilities typically contain many pneumatically controlled valves, actuators and instruments. Airset devices are commonly used to regulate the supply of air pressure to these components. An airset is a specific type of direct-operated, pressure-reducing regulator with an integral filter. It is often overlooked in design, but proper selection is needed for safe and effective operation, which is critical, because these devices are often used in emergency shutdown and other demanding on/off valve applications.

How airset regulators work

As is the case with any direct-operated regulator, an airset senses and maintains downstream pressure to a required setpoint. In Figure 1, the outlet pressure (blue region) is sensed on the underside of the diaphragm, and the airset regulator uses this pressure to generate force and counteract the spring force on the upper side of the diaphragm. The spring casing (in yellow area) is vented to atmosphere.

When air demand downstream increases, the outlet pressure begins to decrease, causing a corresponding decrease of the force exerted on the underside of the diaphragm. The spring reacts by decompressing until it matches the force exerted by the diaphragm. Because the spring is anchored by an adjusting screw, the only way the spring can decompress is in the direction of the diaphragm.

The diaphragm is attached to the valve plug, so the plug is driven away from the seat, increasing air flow from the inlet region (red area) into the downstream system (blue area). When flow demand is satisfied, the pressure under the diaphragm increases to the airset regulator's setpoint,

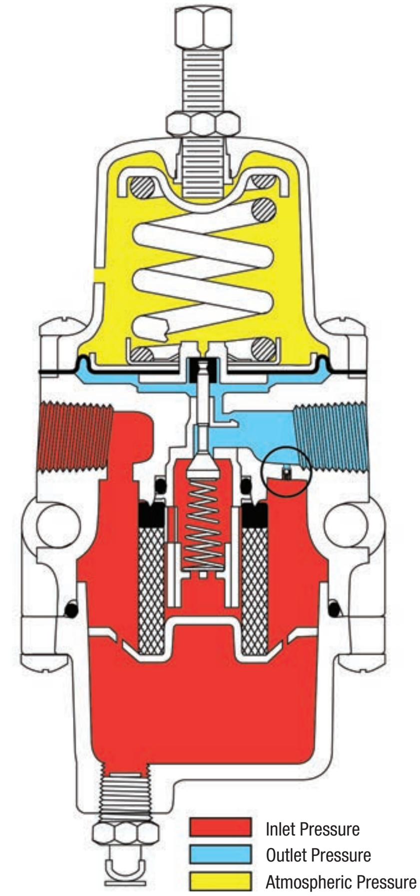


FIGURE 1. A typical airset regulator with integral filter and internal relief is shown here. The outlet pressure (blue region) is sensed on the underside of the diaphragm, and the airset regulator uses this pressure to generate force and counteract the spring force on the upper side of the diaphragm. The spring casing (in yellow area) is vented to atmosphere

the spring compresses, and the valve plug is driven toward the seat to shut off flow.

The regulator is set by adjusting the spring tension. The tighter the spring, the higher the regulator outlet pressure. In operation the regulator will open as much as necessary to maintain the downstream pressure. The diaphragm and spring forces

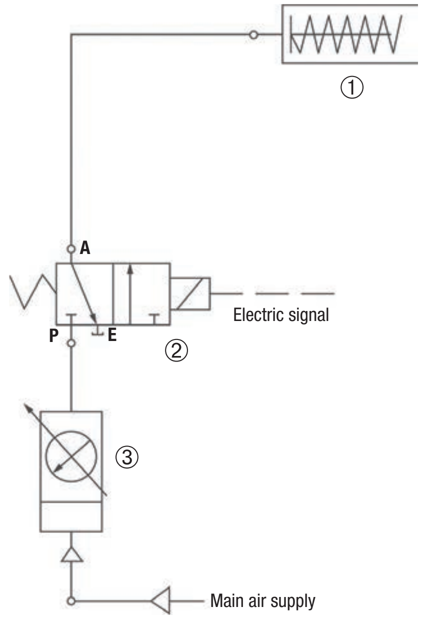


FIGURE 2. In this on/off application, the main air supply pressure to the actuator is controlled to the desired setpoint by the airset (3). This lower pressure air then passes through the solenoid valve (2) and is applied to the actuator (1)

should be in equilibrium when the airset regulator is in a stable mode of operation.

Airset applications

Airset regulators are typically the most common type of pressure regulator used in chemical plants and petroleum refineries. Most notably they can be found attached to control valves, where the airset regulator is used to reduce the system air pressure to a safe operating level for valve operation. A positioner/controller can then send the appropriate pressure to the actuator based upon the setpoint signal, typically received from the automation system. The output results in controllable valve travel to regulate a process flow.

Many applications do not utilize a positioner/controller to regulate valve travel and therefore process flow, but instead require a valve to be either completely opened or closed. These are often referred to as automated on-off valves, where the instrument air pressure is reduced by an airset, and a solenoid downstream of the regulator controls the pressure acting on the valve actuator. The solenoid can release this air pressure to atmosphere in the event the valve is required to fail safe, typically driven to this position by a spring.

Figure 2 shows an example of an airset regulator used in an on/off application. The main air-supply pressure to the actuator is controlled to the desired setpoint by the airset (3). This lower pressure air then passes through the solenoid valve (2) and is applied to the actuator (1).

In petroleum refineries, for example, on/off valves are used in several different systems, including crude distillation, hydrocrackers and hydrotreaters, catalytic crackers and hydrogen generation. In these systems, on/off valves are used to isolate fuel, feedstock and fractionator lines, pumps and flare lines — and to manage reactor depressurization. Airset regulators control airflow to the actuators of these isolation and control valves.

These valves need to stroke on and off in time intervals specified by the end user and depending on the application (Figure 3).

The airset regulator must provide sufficient pressure to stroke these valves for these intervals, while keeping the valve shut when required, and allowing the valve to be repositioned as required.

Airset regulators in SISs

A safety instrumented system (SIS) operates independently of the basic process control system and is used to implement one or more safety instrumented functions. These systems use specialized hardware and software controls, and are governed by the IEC 61511 standard, issued by the International Electrotechnical Commission (www.iec.ch). An SIS performs necessary safety functions to provide protection for personnel and equipment from specific hazards or events.

An SIS is essential in chemical plants and refineries to prevent the outbreak of fire, the release of hazardous materials, and uncon-

trolled flooding. Typical applications and locations for an SIS in a refinery include atmospheric distillation (bottom line of a distillation tower), catalytic cracking (spent catalyst withdrawal and fractionator bottoms), and tank farms (lines for filling or unloading tanks and terminals).

Most of these and other critical applications include emergency shutdown (ESD) on-off valves designed to shut off a flow of process media when dangerous conditions are detected. These valves must be able to operate in an emergency, serving as a system's last line of defense, regardless of whether instrument supply pressure is available.

IEC 61511 requires the application of a three-way solenoid between the airset regulator and the actuator, but it is considered best practice to not rely solely on the solenoid to make sure the valve fails to the correct position.

FIGURE 3. A ball valve with airset regulator and actuator is shown here

Instead, ESD applications require the end user to consider additional selection criteria when determining the correct airset regulator.

Since airset regulators operate based on changes in downstream rather than upstream pressure, it can be problematic for SIS on-off applications if the airset is locked in position because there is no demand to the actuator and instrument supply pressure is lost. The regulator will not react because pressure downstream of the airset remains unchanged unless the solenoid removes the actuator pressure.

If the solenoid downstream of the regulator fails to react, the pressure downstream of the airset may not change, preventing the valve actuator from venting and inhibiting movement to the desired fail position. This situation compromises the entire purpose of the ESD valve and may prevent the SIS from accomplishing its purpose.

Fortunately, there are multiple ways to deal with this issue, as will be explained in the subsequent section.

Selection considerations

When selecting valves and related components for process applications, users must consider inlet and outlet pressure requirements, accuracy, required flow, properties of the process media, pipe size, and temperature rating. But for airset regulators, product type is another important criterion required for appropriate selection. For ESD and other critical on-off applications, it is important to select an airset regulator that can remove trapped air pressure quickly to ensure the valve fails to the appropriate position.

In general, two common types of airset regulators are selected to ensure the proper failure modes of the ESD valves: constant-bleed and integral check valve.

Airset regulators with a constant internal or external bleed prevent pressure from becoming trapped within the valve actuator by constantly bleeding downstream pressure, ensuring the valve fails to the desired position in the event air supply is lost. Constant-bleed airset regulators have been used for decades but are falling out of favor because of these inherent drawbacks:

- Their small bleed orifice will slowly remove actuator pressure and return the valve to the failure position over time, but quick operation is often required
- Constant bleeds continually use plant air, increasing operational costs
- Continuous fugitive emissions result when gases are used to actuate the valve, as opposed to air. This situation can occur in remote oil or natural gas platforms, where it isn't uncommon for valves to use natural gas for actuation pressure. There is often no source of compressed air at these facilities, but natural gas is available at high pressure. This gas is diverted from the well, liquids are knocked out, and the pressure is regulated as required to actuate pneumatic valves and transmitters.

Manufacturers have developed airset regulators with an integral check valve to address the drawbacks of the constant-bleed solution. This integral check valve is located inside the airset body and is closed during normal operation, as shown in Figure 4. In the event of a loss of supply pressure, or if supply pressure drops below the regulator setpoint by a preset amount, the check valve opens and allows the outlet pressure to quickly flow back through the regulator body to

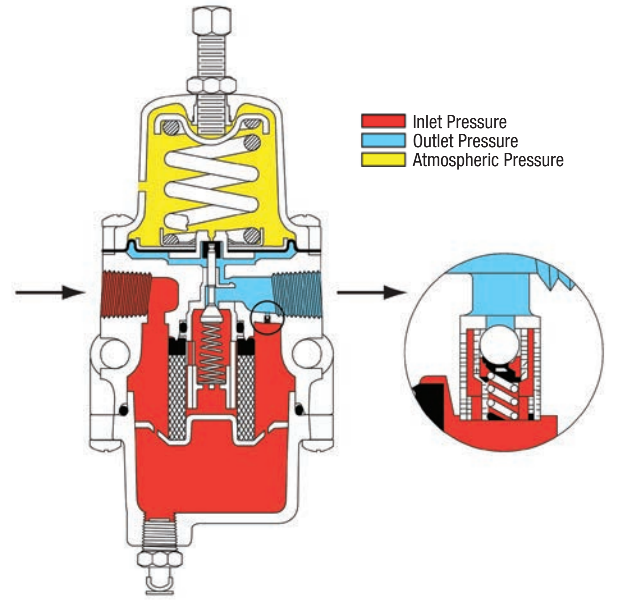


FIGURE 4. This airset regulator with an internal check valve, shown at right, is suitable for emergency shutdown and other on/off applications

the upstream side.

The orifice size of the check valve is larger than the constant-bleed orifice, which ensures fast valve reaction to losses of supply pressure. The check valve also provides a no-bleed solution, resulting in more efficient and safe operation with reduced emissions.

The design eliminates excess air or gas consumption, conserving plant resources. If natural gas is used for actuation, it will not vent to the atmosphere. These types of fugitive emissions can lead to adverse environmental consequences and result in fines.

One drawback of the integral check valve solution is the inability of the airset regulator to fully shut off. These types of airsets require an internal relief valve in order to prevent downstream pressure from slowly climbing due to leaks through the check valve's metal seat.

Recent innovations to airset regulators with internal check valves have added soft seats to the check valve. This allows for bubble-tight shutoff and eliminates the need for a downstream relief to vent off the excess pressure caused by seat leakage over time. It also prevents pressure buildup, which in the worst case, could actuate the valve when not intended.

This type of integral check valve should be specified to prevent downstream pressure from slowly building until it relieves to the atmosphere, or potentially tripping a high-pressure alarm. This design is preferred when supplying air to a dead-ended system, as is the case when supplying a valve actuator. As an added benefit, these devices further reduce system air consumption, along with the corresponding costs of powering these pneumatic devices.

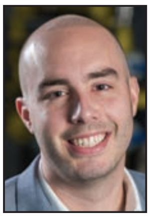
As with all critical components, vendors can provide assistance with selection, ensuring the right regulator is used in a particular application to ensure long asset life with correct operation. ■

Edited by Gerald Ondrey

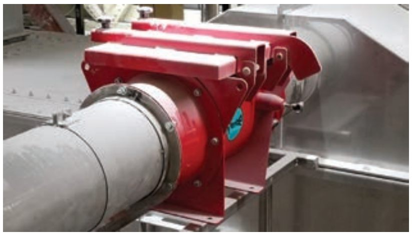
Acknowledgement

All figures courtesy of Emerson.

Author



Jeff Welch is a regional sales manager at Emerson Automation Solutions (3200 Emerson Way, McKinney, TX 75070; Phone: 800-558-5853; Email: jeff.welch@emerson.com). He has nine years of experience with pressure regulators in natural gas, industrial and propane applications. During his time with Emerson, he has worked in test and evaluation engineering, applications engineering, and business development. He has bachelor's degrees in biology and biological engineering from the University of Arkansas.


Rembe GmbH Safety + Control


ARCA Regler


ARI-Armaturen Albert Richter

Valve World Expo Düsseldorf will take place in Halls 1, 3 and 4 of the Düsseldorf, Germany fairgrounds from December 1 to 3, 2020. In Hall 1, the Valve World Conference will also run in parallel with the exposition. Here is a small selection of products being exhibited at the show.

Isolation valve prevents explosion propagation

The Q-Flap NX inlet explosion-isolation valve (photo) is this company's latest generation of inlet-isolation valves to prevent explosion propagation through ductwork. This improved version features magnets that hold the flap open and significantly reduce the pressure drop across the valve. This means that the suction from the dust collector only moves the product. Energy is saved since fans require less power, and product flow is improved by the dramatic reduction in pressure drop. In addition, this optimal system design allows for up to two elbows in ductwork prior to valve installation, which eases the retrofitting process. The optional auto-cleaning feature reduces downtime and speeds up cleaning. The Q-Flap NX meets or exceeds NFPA Standards requirements. It is available in carbon- or stainless-steel construction, with valve sizes ranging from 3 to 40 in. Hall 3, Stand E39 — *Rembe GmbH Safety + Control, Brilon, Germany*
www.rembe.com

Modern machining methods reduce maintenance costs

The valve plug and seat ring are the parts that are exposed to the highest flow velocity and thus the highest mechanical stress. Depending on the process conditions, the plug and seat ring are therefore typical wear parts that sometimes need to be replaced. For valves with standard bonnets, especially when the valve size is DN 100 (4 in.) and smaller, the plug and valve stem are very often designed as one piece. In such cases, the plug, including the stem, will be replaced. For valves with bellows seal or with (cryogenic) extended bonnets, the plug and stem are normally separate parts. In contrast to on/off valves, modulating control valves require a well aligned and rigid connection between the valve plug and stem to prevent vibration damages and to ensure the control performance and tightness of the valve. A very common and proven design involves screwing the valve stem into the plug, usually with an additional cone or corresponding tolerance, to ensure perfect alignment of stem and plug. The main disadvantage of such a design becomes apparent as soon as either the valve plug or the bellows seal needs to be replaced. As the bore for the pin will normally never match the bore in the old stem or plug, spare parts are supplied either as a preassembled plug/stem unit or as individual parts, but without the bore. The first alternative is quite costly, the second alternative requires end users to drill the hole themselves. This company has taken up this challenge and developed special manufacturing equipment and precise CNC (computer numerical control) machining methods to eliminate this disadvantage. Since the middle of this year, all of this company's valves with bellows seal or cryogenic extension bonnets have fully interchangeable plugs and spindles (photo). This means that for all valves built since that date, any replacement stem and plug is supplied fully machined, including the taper bore, and can be replaced without reworking, even on site. Hall 4, Stand A02 — *ARCA Regler GmbH, Tönisvorst, Germany*
www.arca-valve.com

A triple offset valve handles a wide temperature range

Zetrix is a triple-offset, metal-seated process valve. The rotating shaft of the disc is offset from the center line of the disc seat and body seal (first offset) and the pipe's center line (second offset). With triple-offset process valves, the seat's axis of rotation is also asymmetrically opposed to the pipe axis (third offset). The valve is available with butt-weld ends in sizes from 3 to 24 in. (DN 80 to 600), and with a double-flanged design up to DN 1200. The butt-weld design handles temperatures from –60 to 427°C. Hall 3, Stand C52 — *ARI-Armaturen Albert Richter GmbH & Co. KG, Schloß Holte-Stukenbrock, Germany*
www.ari-armaturen.com ■

Gerald Ondrey

Special Control Valves and Actuating Systems

WELLAND & TUXHORN is your reliable partner for Special Control Valves in power plants, industrial plants and chemical/petrochemical plants, such as: HP- and LP- turbine bypass systems, turbine emergency stop valves, turbine control valves, steam conditioning valves, feedwater control valves, minimum flow control valves, cooling water injection valves, boiler start up valves, boiler blow down valves, desuperheater systems, hydraulic and pneumatic actuating systems.

W&T supports the customer to reduce CO_2 by process optimization. The company is distinguished by know-how, persistence, openness to new assignments and the highest developmental and quality standards, which makes the products equally well-known, both domestically and abroad.

Research and development co-operation with scientific and technical institutes creates new theoretical knowledge which is used directly in production, and in optimizing valves currently available.

PRECISION & PROGRESS: First-class in quality and long life

For over 100 years, the highest degrees of precision, quality workmanship and long useful life have defined the product development and production. The robust, impervious and solid construction assures optimal performance and availability.

The consistently high degree of product quality is a result of solid concepts. In addition, a well-thought-out chain of quality assurance measures ensure the long service life of the products. Ongoing supervision of technical drafting designs, manufacturing inspections, strict testing of materials, as well as thorough documentation of the pressure and leakage tests: these are only a few examples of strict quality standards at Welland & Tuxhorn.

The long-standing quality assurance and quality management system, certified according to DIN ISO 9001 and other international guidelines, guarantees highest product quality. W&T is regularly inspected by renowned inspection agencies and is in compliance with all regulations.

TAILOR-MADE SOLUTIONS: Safety for all projects.

The cutting-edge and highly-specialized engineering and production enable W&T to achieve a high level of quality in their fittings. Each and every design concept takes the individual customer's specifications into account.

The newest technologies and a highly-qualified team provide the optimal prerequisites for individual special made-to-order and low-volume production.

W&T service guarantee:

- The high level of quality and functional standards of "Made in Germany" products.
- Consistent focus of the processes toward customer solutions within this specialized market.
- Comprehensive know-how in the fields of steam control and conversion. From valves (including actuators) to switches, to peripheral circuit systems – W&T creates the overview!

www.welland-tuxhorn.de

More than a Check Valve… It's a Check-All!

Since 1958, **Check-All Valve Mfg. Co.** has manufactured a complete line of in-line spring-loaded piston-type check valves. With world wide service, Check-All Valve serves a wide range of industries including the biodiesel, ethanol, chemical, petrochemical, pharmaceutical, food and beverage, water treatment and many others.

The Flange Insert Valve seen here fits between Class 150, Class 300 or Class 600 flanges and uses the pipe as the valve body making it light weight. It has a supply-side spring so the valve trim is upstream of the mixture. It also has tight seals available in common or exotic elastomers for special conditions and you can choose from a variety of spring settings from 1/8 PSI to 100 PSI settings.

With many series available, Check-All Valve provides check valves for practically every service application. Valves are offered with metal-to-metal or soft seats in sizes ranging from 1/8 inch NPT to 20 inch flanged connections. Pressure ratings are available from full vacuum to 10,000 PSI. Standard or exotic materials are available and you can choose from a wide variety of spring settings for any valve. Most options are available for fast delivery. See us at **www.checkall.com**

Absolute Zero Leakage Control Valves for Liquid and Gas

Kepner's proven Flexible Seal Seat™ design offers positive shutoff of liquid or gas as confirmed by helium leak testing. The seat design is a carefully engineered combination of metal-to-metal and resilient O-ring seal contact. The O-ring is securely retained at the seat rather than on the poppet, protecting it from the destructive abrading and blasting effect of the flow. The result is a design that holds up to extended harsh cycling where competing "soft seat" valves wear and fail.

Kepner Products Company's Flexible Seal Seat™ valves are available in both inline and cartridge insert styles, providing check, relief, shuttle and pilot operated check functions. An extensive selection of port options, materials and flow ranges up to 500 GPM provide over 100,000 product configurations that cover a wide range of pressures, temperatures and media types. Kepner also provides value-added services, custom designs and special testing to meet specific requirements. For more details visit our website. **www.kepner.com**

Economic Indicators

2018 2019 2020

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Aug. '20 Prelim.	July '20 Final	Aug. '19 Final
CE Index	594.1	593.6	602.2
Equipment	718.0	718.8	731.7
Heat exchangers & tanks	608.2	613.0	639.8
Process machinery	718.3	719.8	723.8
Pipe, valves & fittings	955.3	945.8	954.1
Process instruments	416.9	415.9	412.8
Pumps & compressors	1084.0	1083.5	1071.6
Electrical equipment	563.5	563.1	559.6
Structural supports & misc.	756.1	760.8	781.6
Construction labor	340.8	337.4	337.6
Buildings	601.7	594.2	591.8
Engineering & supervision	312.1	312.2	314.5

Annual Index:

2012 = 584.6

2013 = 567.3

2014 = 576.1

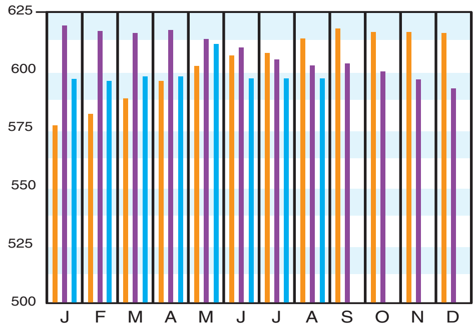
2015 = 556.8

2016 = 541.7

2017 = 567.5

2018 = 603.1

2019 = 607.5

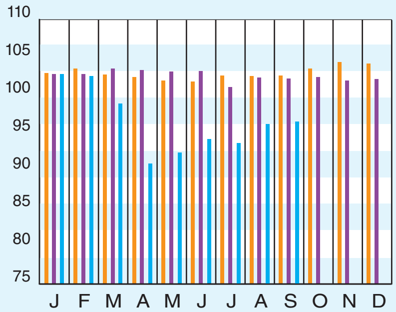


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

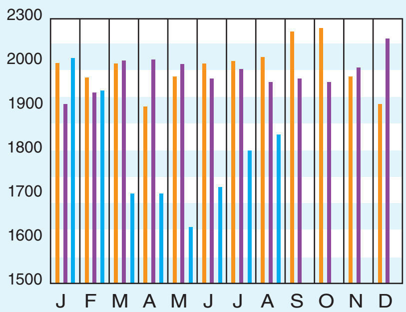
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Sept. '20 = 96.2	Aug. '20 = 96.1	Jul. '20 = 94.2	Sept. '19 = 102.4
CPI value of output, $ billions	Aug. '20 = 1,836.9	Jul. '20 = 1,808.9	Jun. '20 = 1,768.1	Aug. '19 = 2,017.5
CPI operating rate, %	Sept. '20 = 71.8	Aug. '20 = 71.6	Jul. '20 = 70.1	Sept. '19 = 76.3
Producer prices, industrial chemicals (1982 = 100)	Sept. '20 = 227.3	Aug. '20 = 219.5	Jul. '20 = 217.6	Sept. '19 = 242.5
Industrial Production in Manufacturing (2012 =100)*	Sept. '20 = 98.3	Aug. '20 = 98.5	Jul. '20 = 97.4	Sept. '19 = 104.5
Hourly earnings index, chemical & allied products (1992 = 100)	Sept. '20 = 192.4	Aug. '20 = 188.5	Jul. '20 = 189.8	Sept. '19 = 184.6
Productivity index, chemicals & allied products (1992 = 100)	Sept. '20 = 102.3	Aug. '20 = 100.5	Jul. '20 = 100.8	Sept. '19 = 97.0

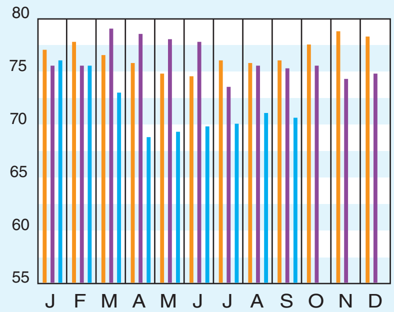
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for August 2020 (the most recent data available) increased by a small margin compared to the previous month's value. It was the second straight increase after a three-month period of declining values. Increases in two of the four major subindices — namely Construction Labor and Buildings — offset very small decreases in the Equipment and Engineering & Supervision subindexes to arrive at the overall higher CEPCI value, which now sits at 1.3% lower than the corresponding value from August of last year. Meanwhile, the Current Business Indicators (CBI; middle) showed a relatively stable CPI Output Index and CPI Operating Rate for September, each rising slightly.